CHAPTER 6
TRICKLING BIOFILTERS
(ATTACHED GROWTH AEROBIC TREATMENT SYSTEMS)

The biological treatment of wastewater with a trickling biofilter is among the oldest and most well characterized technologies. These systems have also been described as intermittent (medium) filters, packed bed filters (PBFs), trickling filters (TFs), attached growth processes, and fixed film processes.

The fundamental components of the trickling biofilter system are (1) a medium upon which a microbial community (biofilm) develops, (2) a container or [lined] excavated pit to house the medium, (3) a system for applying the water to be treated to the medium, and (4) a system for collection and distribution of the treated water. The water to be treated is applied, periodically, in small doses to the medium. Trickling biofilters can be operated in single-pass or multi-pass configurations, as described below.

Single-pass systems
In a single-pass system, the water to be treated is only applied to the biofilter one time before being collected and conveyed to subsequent treatment or dispersal. In some cases, with appropriate topography and land area, it may be possible to operate without, or with minimal, pump usage.

Multi-pass systems
Repeated application of the water to be treated to the biofilter before release to subsequent treatment is known as a multi-pass system. After a dose of the water to be treated passes through the biofilter, a portion (return flow) is returned to the septic tank or intermediate storage for reapplication, and the remainder (effluent) is discharged to subsequent treatment. The return flow is combined with the process influent water (typically effluent from a septic tank) before reapplication to the biofilter. The combining of the return flow (treated) with the process influent (untreated) results in a combined water with intermediate quality. Due to the dilution of the process influent, the hydraulic loading rate (HLR) can be increased and the overall filter surface area decreased relative to the single-pass system. Because of the need for repeated application (recirculation) of the wastewater, pumping and control system needs may be increased, as compared to single-pass systems.

Other configurations
Other configurations for trickling biofilters include dosing at intermediate depths within the biofilter medium, bottomless containers that allow biofilter effluent to infiltrate directly into the soil, the separate treatment of greywater and blackwater (for improved denitrification), and placement of the biofilter inside of the septic tank.

System components
The most common components of trickling biofilter systems are discussed below. For both single-pass and multi-pass systems, the system components include (1) a support medium for the attached biofilm, (2) a wastewater distribution system for the biofilter material, (3) a container for the biofilter material, and (4) a collection system for the water after it has passed through the biofilter.

Support medium
Trickling biofilter systems are primarily distinguished by the material that is used to support the active microbial community. Variations in material properties such as surface area, infiltration capacity, and porosity can have a significant impact on the operation and performance of the system. The categories of media used in trickling biofilters (discussed in Secs. 6-1 to 6-3) are (1) inorganic granular, (2) organic, and (3) synthetic.

Distribution system
The primary methods for applying wastewater to the biofilter for treatment are the (1) orifice system and the (2) spray system. For the orifice distribution system, a layer of pea stone is often included on the surface of the filter medium to promote the lateral distribution of wastewater. For high infiltrative capacity media, the need for uniform distribution of wastewater to the surface of the filter has led to the use of closer orifice spacing for the orifice distribution system and full-cone spray nozzles for the spray distribution system. When media with a high infiltrative capacity are used, increasing the orifice density (i.e., closer together) or the use of spray distribution is recommended.

For gravity flow systems, dosing siphons may be used to perform the periodic application of wastewater. Pressure dosed systems are required when there is insufficient slope for gravity flow and when additional process control is desired. Pressure dosed systems can use high or low head pumps, timing devices, and float switches/alarms.

Container
Various containers have been used to house the support medium for the attached microbial community, including plastic, fiberglass, concrete, and PVC lined pits. In some installations, the biofilter has been integrated into the landscape using decorative bricks and/or used as a raised bed planter. For lightweight materials, such as synthetic media, in high groundwater areas, care should be taken to ensure that the tank does not become buoyant under high groundwater conditions.

Collection system
The collection system specified depends on the type of biofilter medium used. For granular media filters, the most common type of underdrain is a slotted PVC pipe covered by a coarse gravel or rock drain layer and an intermediate sized gravel layer. The active filter material is then placed on top of the intermediate sized gravel layer, to limit the granular biofilm support material from migrating into the underdrain system. For lightweight synthetic materials, a less complex system can be used, such as a support screen above an effluent drain.

Tankage
Additional vessels may be needed depending on the type of system, including pump basins, mixing and recirculation tanks, and equalization basins. Equalization is used to normalize highly variable flows and can occur in a separate tank or in the septic tank. Mixing and recirculation tanks can include intermediate tanks for temporary storage and mixing of water to be reapplied to the biofilter (multi-pass systems). Pump basins may be used for dosing the biofilter or delivering biofilter effluent to a soil adsorption area.

Control systems
Dosing of trickling biofilters can be accomplished on a timed dosing or on-demand basis. The timed dosing regime offers the advantage of even application of wastewater to the biofilter, resulting in improved performance. Given the typical variation in residential water use, the timed system is recommended to obtain more even dosing of wastewater.

Operational parameters
The performance of trickling biofilters is dependent on several process control variables, including hydraulic loading rate (HLR), organic loading rate (OLR), hydraulic application rate (HAR), dosing frequency (DF), and recirculation ratio (α). Each of these terms is defined below.

Hydraulic loading rate
In single-pass systems the HLR is equal to the volume of wastewater per unit time applied to the biofilter medium. The most common expression for the HLR is gallons of wastewater applied per ft^2 of biofilter surface area per day ($gal/ft^2 \cdot d$). For the multi-pass systems, the HLR

is equivalent to the volume of filter effluent produced, i.e., leaving the system, per unit time. It should be noted that, due to the multiple application of the wastewater to the filter, the actual volume of water applied to the biofilter surface is greater than the HLR by a factor equal to α, as discussed below. The peak HLR should be used for system design purposes.

Organic loading rate

The organic loading rate (OLR) is a measure of the oxygen demanding compounds (soluble and particulate organic materials) applied to the biofilter on an area basis. The OLR is calculated by multiplying the 5 day biochemical oxygen demand (BOD_5) or chemical oxygen demand (COD) by the HLR and an appropriate unit conversion factor. The OLR is an estimate of the amount of organic material that is being processed by the microbial community. For wastewaters that have a significantly higher organic concentration (i.e., high BOD_5), sizing the treatment process based on the HLR may result in organic overloading. Typical units for the OLR are lb $BOD_5/ft^2 \cdot d$.

Dosing frequency

The number of applications of wastewater to the biofilter surface over a specific time period is described as the dosing frequency (DF). The DF is selected based on the specific configuration and operation of the treatment system. In general, it has been determined that applying small doses more frequently (i.e., increased DF) improves the performance of trickling biofilters.

Hydraulic application rate

The hydraulic application rate (HAR) is used to characterize the size of the dose applied to the biofilter. The hydraulic application rate is defined as:

$$\text{HAR, in/dose} = \frac{(0.01114)(\text{Hydraulic loading rate, HLR, gal/ft}^2 \cdot \text{d})(1+\text{Recirculation ratio, } \alpha)}{(\text{Dosing frequency, DF, dose/d})}$$

For single-pass systems, the recirculation ratio is equal to zero, and thus only needs to be considered for multi-pass systems. The recirculation ratio is discussed below.

Recirculation ratio

For multi-pass systems, α is defined as the statistical number of times that the wastewater is applied to the biofilter surface before being returned to the recirculation tank or released as effluent from the system. Values for α are typically in the range from 2:1 to 9:1. Reduced denitrification has been observed when high recirculation is used due to the increased volume of oxidized water returned to the anaerobic/anoxic treatment process. Alternately, low values of α may result in insufficient contact time for meeting treatment objectives and intermittent odor problems.

Failure

System failure can be attributed to operational problems and to equipment failure. Equipment failure can include pump breakdown, power outages, control system malfunction, or a tripped circuit breaker. High water alarms can be used to provide warning in case of equipment failure. Operational problems may be due to organic, solids, or hydraulic overloading; inadequate design or construction; extreme temperatures that inhibit biological growth; or other situations that result in ponding of wastewater on the biofilter surface. When an operation problem causes wastewater to accumulate on the biofilter surface, several actions may be taken to renovate the problem, including excavation and replacement of part or all of the media and adjusting the operational features (e.g., reduced hydraulic or constituent loading, increased dosing frequency). In cases where the medium in a failed system has not replaced, it has been observed that several weeks may be required for the effluent quality to return to normal.

Monitoring and maintenance
A monitoring and maintenance program is recommended for all systems to ensure long-term treatment performance. Monitoring procedures should include regular (about every 3 months) inspection of system components, operation, and effluent quality.

System components
The system components to be inspected include the control panel, pumps, pump basins, float switches, dosing siphons, and media surface. Any electrical power and control components that are not working properly should be serviced or replaced. Solids that accumulate in pump basins should be pumped out regularly, typically at the same time that solids are pumped from an upstream septic tank.

Operation
System operation should be monitored to ensure that overloading is not occurring. System operational parameters to be checked may include pressure in the distribution system during dosing, hydraulic application rate, and surface accumulations. Accumulation of solids or water on the surface of the media is an indication that the operational parameters need to be adjusted. The surface layer of the filter may be raked or excavated if necessary. If clean-out ports have been installed, the distribution system can be flushed to remove solids that have accumulated.

Effluent quality
System performance can be monitored by inspecting the effluent quality. The two types of analysis are qualitative (sensory analysis) and quantitative (lab analysis). In most cases a qualitative analysis should be sufficient to determine if the system is functioning correctly. To perform a qualitative analysis, the water sample is collected from an appropriate effluent sampling port into a clear glass container. If a valve is opened to dispense the sample, it should be allowed to flow for a short period to flush solids that have been dislodged. A properly operating secondary treatment process, such as a trickling biofilter should have minimal suspended material and be free of offensive odors. If quantitative analysis is desired, the samples should be handled in a manner consistent with Standard Methods for the Examination of Wastewater (2000).

6-1 Granular media trickling biofilters
In the original trickling biofilter systems, sand was used as the medium for attached biofilm growth. Because of its availability and historical utilization, sand is still one of the most commonly used media in trickling biofilters. Other granular inorganic media that are used include gravel, crushed glass, expanded aggregates, and slag.

While granular materials have performed well in trickling biofilter systems, there is a correlation between media properties and system performance and failure. The material needs to be relatively free of fine material that can result in the formation of a clogging lens within the biofilter. In addition, the material needs to have sufficient surface area and matrix properties to support the biofilm. The infiltrative capacity of the medium may also be useful in assessing the relative ability of the material to accept the applied wastewater.

6-1.1 Activated carbon biofilter

Category	Secondary/tertiary treatment
Technology	Trickling biofilter, adsorption
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background
Activated carbon is a high surface area material used for adsorption of various compounds. While not commonly used in biofilter applications, activated carbon may be an effective material for the adsorption of microorganisms as well as wastewater constitutes. Additional research is needed to characterize the performance of activated carbon for the tertiary wastewater treatment.

Operation and maintenance
After reaching its adsorptive capacity, the carbon can be regenerated or replaced. Cost needs to be evaluated to determine if process is feasible.

Contact
Activated carbon is widely used for air treatment and drinking water treatment. Local suppliers are available in most areas.

References and other resources
Stevik T.K., G. Ausland, P. Jenssen, and R.L. Siegrist (1999) Removal of E. Coli During Intermittent Filtration of Wastewater Effluent as Affected by Dosing Rate and Media Type, *Water Research*, Vol. 33, No. 9, pp. 2088-2098.

6-1.2 AIRR™ wastewater recovery system

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background
The alternating intermittent recirculating reactor (AIRR) is a trickling biofilter with a sand/gravel medium. The process was developed in 1977, and the original installations are still in operation.

Description of process
The biofilter is divided into two sections, a treatment section and a polishing section. Septic tank effluent is collected and distributed to the treatment biofilter section of the system. After passing through the treatment biofilter, the water is collected and applied to both the treatment biofilter and the polishing biofilter. The portion of the water applied to the treatment biofilter is returned for recirculation flow, and the effluent that passes through the polishing biofilter is discharged. The concept is that it is not possible for water that has not passed through the treatment biofilter to be applied to the polishing biofilter for discharge.

Performance
Manufacturer reports typical effluent concentrations of BOD_5 and TSS in the range of 2 to 3 mg/L.

Operation and maintenance
Manufacturer provides operation and maintenance instructions to system owner. Recommend maintenance on an annual basis. Systems have been successfully operated in both hot and cold climates.

Contact
SPEC Industries, Inc.
550 Parkson Road
Henderson, NV 89012
Phone (702) 558-4444
Fax (702) 558-4563
E SPECindustries@juno.com

References and other resources
U.S. EPA (2001) *CEIT Virtual Trade Show: AIRR Wastewater Recovery Systems (available at www.epa.gov/region1/steward/ceitts/wastewater/techs/airr.html).*

6-1.3 Ashco-A RSF III™

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Contact
Ashco-A-Corporation
1946 Grafton Rd.
Morgantown, WV 26508-0000
Phone (304) 291-0808
Fax (304) 291-0843
Model description
RSF II (cluster systems and commercial applications)
RSF III (single unit residential systems)

6-1.4 Crushed brick biofilter

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background
Crushed red brick has been found to have enhanced phosphorus removal capacity when placed beneath a drip irrigation system (Anderson, 1998). Similar results could be expected when using this material in a trickling biofilter or related application.

Description of process
A lined bed of crushed brick is periodically dosed with septic tank effluent. The crushed brick serves as a medium for microbial attachment and adsorbs excess phosphorus from the wastewater.

Performance
A lined crushed brick biofilter was evaluated by Ayers Associates as part of the Florida Keys Onsite Wastewater Nutrient Reduction System Demonstration Project. The crushed brick biofilter was expected to have excellent phosphorus adsorption capability for 10 years (Florida Dept of Health, 2000). Additional research is needed to evaluate the phosphorus removal capability of locally obtained crushed brick.

Operation and maintenance
Phosphorus adsorption will eventually reach capacity and will require the medium to be regenerated or replaced. The medium may be useful as a soil amendment.

Contact
Locally available in many areas, check local landscape supply outlets.

References and other resources
Anderson D.L., M.B. Tyl, R.J. Otis, T.G. Mayer, and K.M. Sherman (1998) Onsite Wastewater Nutrient Reduction Systems (OWNRS) for Nutrient Sensitive Environments, in *Proceeding of the Eight National Symposium on Individual and Small Community Sewage Systems, Orlando, FL.*

Florida Department of Health (2000) *Florida Keys Onsite Wastewater Nutrient Reduction Systems Demonstration Project – Phase II Addendum*, Florida Department of Health.

6-1.5 EnviroFilter™ modular recirculating media filter

Catagory	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single residential and small community/institutional systems

Background
The EnviroFilter developed by Earthtek Environmental Systems, Inc. is a self-contained trickling biofilter system. The system offers the advantage of not requiring a detailed engineering design due to its pre-packaged nature. All system components come pre-assembled and housed in a container, minimizing installation costs.

Description of process
The basis of the EnviroFilter design is a multilayer biofilter. The biofiltration media is layered to reduce the overall footprint of the system. Currently the system utilizes a granular medium to support fixed film growth; however, future development may include the use of high porosity synthetic materials.

Performance
The EnviroFilter unit includes a recirculation feature that can be expected to contribute to additional total nitrogen removal. Manufacturer reported performance values are presented in Table 6-1.

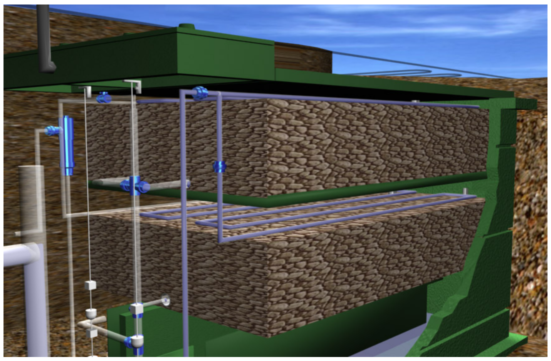
Table 6-1
Typical performance of the EnviroFilter treatment system[a]

Parameter	Removal efficiency
$CBOD_5$	98%
TSS	98%
TN	70%
Fecal coliform	2 logs

[a] Adapted from manufacturer brochure.

Operation and maintenance
System should be inspected periodically to ensure proper operation. Pumps and control devices will need periodic inspection and servicing as required. Standard drip irrigation system will need to be flushed.

Cost
Total cost for complete system installer (including septic tank and drip irrigation system) in the range to $11,000 to 13,000.



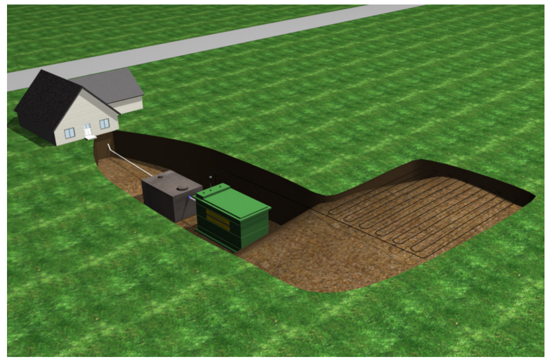


Figure 6-1
EnviroFilter modular treatment unit cutaway view showing multi-layer design (left) and installed system with drip irrigation system (right). (Adapted from Earthtek Systems, Inc.)

Earthtek Environmental Systems, Inc.
204 South St.
Batesville, IN 47006
Phone (812) 934-5035
Fax (812) 934-5018
E kchaffee@earthtekonline.com
Web www.earthtekenvironmental.com
Earthtek Environmental Systems, Inc.
Model descriptions
EnviroFIlter 500B (3 bedrooms)
EnviroFIlter 600B (4 bedrooms)
EnviroFIlter 750B (5 bedrooms)
Vendor support
Manufacturer recommended/required service contract.

6-1.6 Eparco

Category	Secondary treatment
Technology	Trickling biofilter
Input	Untreated wastewater
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background
Eparco manufactures complete wastewater treatment systems for individual homes and communities. The system consists of a specially designed primary treatment module (septic tank), a pre-treatment module, a compact treatment biofilter, and a tertiary sand biofilter. The Eparco system is gravity flow and operated in series similar to a single-pass sand biofilter system.

Performance
Typical effluent quality of BOD_5 and TSS concentrations less than 5 mg/L, nitrification, and some nitrogen removal. The system does not incorporate a distinct denitrification step.

Operation and maintenance
Passive process that requires little regular operation and maintenance. Manufacturer guarantees septic tank will not need pumping for 4 to 10 years.

Contact
Eparco
5420 North Service Road
Burlington, Ontario, Canada L7L 6C7
Phone (905) 319-8100
Fax (905) 319-1987

6-1.7 Expanded aggregate biofilters

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, and pathogen reduction
Applications	Single home and small community residential systems

Background
When shale, clay, or slate are heated in a rotary kiln at high temperature (1000 to 2000 ^oF), a porous structure develops and is referred to as lightweight expanded aggregate. Expanded aggregates typically have a bulk density of 45 to 50 lb/ft^3, or about 50 percent less than other granular materials such as sand and gravel. Because of the low bulk density, these materials are often referred to collectively as lightweight aggregates (LWA). This material is available at low cost and has been used as an alternative biofilter medium in some cases.

Description of process
Expanded aggregate materials have been used in single-pass and multi-pass biofilter arrangements. These materials have been found to perform well as support materials for the attached biomass in trickling biofilters and as a support medium in constructed wetlands.

Influent should be settled wastewater without high concentrations of particulates or oil and grease. Effluent management will depend on characteristics of the receiving location. Effluent may be distributed through drip irrigation (after disinfection) or other soil treatment system.

System footprint
Typical system will have a surface area of 100 ft^2,based on loading of 450 gal/d of typical settled residential wastewater and an estimated loading 5 gal/ft^2•d. Systems can be installed above ground, partially buried, or fully buried. Top of filter may be planted or otherwise integrated into landscape for aesthetic purposes.

Advantages
Material does not contain the fine materials that are implicated in clogging of sand biofilters. Material is lightweight and cost is competitive with other materials. Excellent phosphorus adsorption properties.

Disadvantages
May require electricity for pump operation. Somewhat limited design specifications available. For systems that rely on pumps, extended power failure can result in wastewater backup.

Performance
The performance of LWAs to remove microorganisms and phosphorus has been documented in several studies. Zhu *et al*. (1997) documented that Utelite (Coalville, UT) LWA had the highest phosphorus adsorption of 12 materials evaluated (3.46 g P/kg of material) and that phosphorus adsorption is dependent on the calcium content of the material. Stevik *et al*. (1999) reported complete E. Coli removal in spiked wastewater samples applied to crushed expanded aggregate biofilter. Additional performance specifications from representative research studies are presented in Table 6-2.

Table 6-2
Selected representative studies of expanded aggregate trickling biofilter performance

Parameter	Unit	Location of study		
		Maryland[a]	Maryland[a]	Florida[b]
Description of system		Expanded shale	Expanded slate	Drip irrigation to 24 in bed of LECA[c]
HLR	gal/ft^2•d			1.35
System performance[d]				
BOD_5	mg/L	20 (92%)	20 (92%)	1 (99%)
TSS	mg/L	36 (67%)		5 (95%)
TN	mg/L	23 (60%)	30 (48%)	29 (39%)
NO_3-N	mg/L			28
NH_3-N	mg/L			0.9
P	mg/L			0.5 (94%)
Fecal coliform	CFU/100 mL	2.9E3 (2)	2.5E2 (3.1)	

[a] Medium known as Filtralite-P™ LECA designed for phosphorus removal.
[b] Anne Arundel County National Onsite Demonstration Project.
[c] Anderson *et al*. (1998) and Florida Department of Health (2000).
[d] Performance reported as average effluent concentration with average removal in parentheses, except microorganism removal, which has logs of removal reported in parentheses.

Operation and maintenance
If expanded aggregates are used for the adsorption of phosphorus, the medium will need to be regenerated or replaced after reaching its adsorptive capacity (estimated 10 year lifespan). Other operation and maintenance is similar to that for other trickling biofilters, including removal of sludge from primary treatment, maintenance of septic tank effluent filtration devices, and inspection of control devices. Expanded aggregates generally have a large enough particle size that surface clogging is not a concern. Systems should be inspected regularly for ponding of wastewater on biofilter surface (or otherwise reduced infiltrative capacity) due to clogging. Correct pump and control system operation should be confirmed. Phosphorus adsorption capability estimated to be 10 years.

Power and control
Treatment system can be operated with or without pumps depending on specific site characteristics and design. Alarm and monitoring equipment recommended. Can be dosed on a timed (recommended) or on-demand basis. Annual power usage expected to range from negligible (no pump/control) to 150 kWh.

Cost
Estimated capital cost $2,000 to 3,000 (LWA currently available in bulk for $40/yd^3$) for treatment system only, additional cost for standard septic system (including effluent management system), engineering and permitting fees, operation, and maintenance.

Contact
Local suppliers can be located by contacting the Expanded Shale, Clay, and Slate Institute www.escsi.org

Optiroc Group
Po. Box 216 Alnabru,
Brobekkveien 84
0614 Oslo, Norway
Phone +47 22 88 77 00
Fax +47 22 64 54 54
Web www.filtralite.com

Scancem AB
PO Box 60066
SE-216 10 Malmö, Sweden
Phone +46 (0)40-16 50 00
Fax +46 (0)40-16 51 43
E info@hq.scancem.com
Web www.scancem.com
Description
LECA and Filtralite-P™ LECA.

TXI - Ontario
3500 Porsche Way Suite 150
Ontario, CA 91764
Phone (909) 635-1880
Fax (909) 635-1899
Web www.txi.com

Utelite Corporation
PO Box 387
Coalville, Utah 84017-0387
Phone (435) 336-5301 or (801) 467-2800
Fax (801) 467-6765
E utelite@allwest.net
Description
One of the best performing materials is manufactured in Utah (Utelite), with an estimated phosphorus adsorption capacity of 3.5 g P/kg of media.

Figure 6-2
LECA material with particle diameter of 0.3 to 0.4 in. (Adapted from Scancem AB.)

Figure 6-3
Utelite expanded aggregate (available in coarse, medium, and fine sizes).

Figure 6-4
Filtralite™ aggregate media. (Adapted from Optiroc Group, Inc.)

References and other resources
Anderson D.L., M.B. Tyl, R.J. Otis, T.G. Mayer, and K.M. Sherman (1998) Onsite Wastewater Nutrient Reduction Systems (OWNRS) for Nutrient Sensitive Environments, in *Proceedings of the 8th National Symposium of Individual and Small Community Sewage Systems* - 2001, American Society of Agricultural Engineers, pp. 235-244, St. Joseph, MI.

Expanded Shale, Clay, and Slate Institute <www.escsi.org>.

Florida Department of Health (2000) *Florida Keys Onsite Wastewater Nutrient Reduction Systems Demonstration Project – Phase II Addendum*, Florida Department of Health.

Heistad, A., P.D. Jenssen, and A.S. Frydenlund (2001) A New Combined Distribution and Pretreatment Unit for Wastewater Soil Infiltration Systems, in *Proceedings of the 9th National Symposium of Individual and Small Community Sewage Systems* - 2001, Fort Worth, TX, American Society of Agricultural Engineers, pp. 235-244, St. Joseph, Michigan.

Johansson, L. (1997) The Use of LECA (Light Expanded Clay Aggregates) for the Removal of Phosphorus from Wastewater, *Water Science and Technology*, Vol. 35, No. 5, pp. 87-93.

Stevik, T.K., G. Ausland, P. Jenssen, and R.L. Siegrist (1999) Removal of E. Coli During Intermittent Filtration of Wastewater Effluent as Affected by Dosing Rate and Media Type, *Water Research*, Vol. 33, No. 9, pp. 2088-2098.

Zhu, T., P.D. Jenssen, T. Maehlum, and T. Krogstad (1997) Phosphorus Sorption and Chemical Characteristics of Lightweight Aggregates (LWA) – Potential Filter Media in Treatment Wetlands, *Water Science and Technology*, Vol. 35, No. 5, pp. 103-108.

6-1.8 Glass (crushed) biofilters

Category	Secondary treatment
Technology	Trickling biofilter (single-pass and multi-pass)
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background
Crushed glass has been evaluated as a biofilter medium in several research projects. Glass is widely available as a product from solid waste recycling programs that often has little value due to the presence of contamination and lack of color separation. Glass crushing equipment can be used to prepare glass of various grades and the crushed glass can be screened to obtain the desired medium specifications. Because of the difficulty in obtaining appropriately sized sand in some areas, crushed glass may be economically preferable.

Description of process
The operation of the crushed glass filter is similar to other aggregate media filters (i.e., sand, gravel, etc.). Most literature reports describe single-pass systems; however, crushed glass has also performed well in multi-pass configurations. In general, increasing dosing frequency and distribution uniformity is believed to improve system performance. Influent should be a settled, typical residential wastewater without high concentrations of particulates, large particles, or oil and grease. A septic tank screening device is recommended. Effluent management will depend on characteristics of the receiving location. Effluent may be distributed through drip irrigation (after disinfection) or other soil treatment system.

System footprint
Typical systems will have a surface area of 400 ft^2. Systems can be installed above ground, partially buried, or fully buried. The top of the filter may be planted or otherwise integrated into landscape for aesthetic purposes.

Performance
The performance of the crushed glass as a medium is not significantly different from the performance of sand, when both materials meet certain size specifications. Crushed glass material generally has a coarse texture (as determined by sieve analysis) and higher infiltrative

capacity than comparable sand used in similar applications. Additional performance specifications from representative research studies are presented in Table 6-3.

Table 6-3
Selected representative studies of crushed glass trickling biofilter performance

Parameter	Unit	Location of study			
		King Co, WA[b]	Oswego, NY[c]	Ronald, WA[b]	Davis, CA[d]
Description of system		Residential	Residential	Residential	Experimental
Pretreatment		Septic tank with outlet filter	Septic tank	Septic tank with outlet filter	Primary effluent
ES (d_{10})	mm	0.24	0.7	0.24	0.44
UC (d_{60}/d_{10})	unitless	7.8	5.6	7.8	5.0
Depth of medium	ft	2	2.5	2	1.25
α	unitless	1	3	1	1
HLR	$gal/ft^2 \cdot d$	1.2	1.8	1.6	1
DF	dose/d	4	n/a	n/a	24
Temp	^oF	55	64	61	
pH	unitless	6.4	7.3	7	
System performance[a]					
COD	mg/L		39.7 (83%)		8 (95%)
BOD_5	mg/L	7 (96%)	10.7 (94%)	7 (97%)	
TSS	mg/L	4 (91%)	2.5 (95%)	4 (94%)	0 (>99%)
Oil/grease	mg/L	6 (79%)		7 (85%)	
TN	mg/L	30 (29%)	19.7 (55%)	29.8 (48%)	
NO_3-N	mg/L	28	12.7	25.8	
NH_3-N	mg/L	<1	4.1	2.1	
Fecal coliform	CFU/100 mL	1.6E3 (2.7)		2.3E3 (3.3)	
Total coliform	MPN/100 mL				4400 (3.4)
Native phage	PFU/mL				2 (3.1)

[a] Performance reported as average effluent concentration with average removal in parentheses, except microorganism removal, which has logs of removal reported in parentheses.
[b] CWC (1997) study of individual residential systems.
[c] Elliott (2001) reported operation and performance of a small community system.
[d] Emerick *et al*. (1997) conducted research project at UC Davis.

Advantages
Medium used is available statewide as a component recovered from solid waste recycling activity, however, use of crushed glass may include cost preparing glass (i.e., grinding and shipping). Design and performance are similar to sand medium.

Disadvantages
May require electricity for pump operation. Somewhat limited long-term performance data available. For systems that rely on pumps, pump failure, control panel failure, and extended

power outages can result in wastewater backup. Improper design, construction, or loading can lead to system failure (ponding of water on surface of biofilter).

References and other resources

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6-1.9 Glass (sintered) biofilter

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background/description

A high surface area material used for fine particle filtration and used in some experimental systems as a medium for biological attached growth.

6-1.10 Gravel biofilter (multi-pass systems)

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background

The multi-pass gravel trickling biofilter has been used for onsite wastewater treatment since its development in the 1970s. The system uses a coarse sand or gravel medium for biofilm growth. Additional details on multi-pass sand/gravel filters are presented in Table 6-4.

Description of process

Multi-pass systems have been configured in a variety of ways, depending on the method of recirculating the filter effluent. As shown in Fig. 6-5, the filter effluent can be recirculated to one of the chambers in the septic tank or to a separate tank (recirculation tank). One or two pumps are required for system operation, depending on the specific design. Influent should be settled wastewater without high concentrations of particulates or oil and grease. Effluent management will depend on characteristics of the receiving location. Effluent may be distributed through drip irrigation (after disinfection) or other soil treatment system.

System footprint
Typical system will have a surface area of 110 ft^2. Systems can be installed above ground, partially buried, or fully buried. Top of filter may be planted or otherwise integrated into landscape for aesthetic purposes.

Performance
Additional performance specifications from representative research studies are presented in Table 6-4. Recirculation and mixing of the filter effluent with septic tank effluent reduces the overall oxygen demand of the water to be treated, allowing for higher loading rates.

Table 6-4
Selected representative studies of gravel (multi-pass) trickling biofilter performance

		Location of study			
Parameter	Unit	Minnesota[b]	Martinez, CA[c]	East Lansing, MI[d]	Gloucester, MA[e]
Description of system		Residential	Community	Residential	Residential
ES (d_{10})	mm		3	0.3	
UC (d_{60}/d_{10})	unitless		<2	4	
Depth of medium	ft	2	2	4	2
α	unitless	5	5	5	5
HLR	$gal/ft^2 \cdot d$	5	3	3.1	3
DF	dose/d			14	
pH	unitless		7.6	7.0	
System performance[a]					
BOD_5	mg/L	18 (93%)	<5 (96%)	6 (96%)	7 (98%)
TSS	mg/L	23 (81%)	4.9 (93%)	2 (95%)	12 (85%)
Oil/grease	mg/L		0		2.3 (94%)
TN	mg/L	43 (47%)	12.6 (80%)	26 (53%)	60.8 (36%)
NO_3-N	mg/L	29	12.2	24	38.8
NH_3-N	mg/L	9	0	2.1	17.5
P	mg/L	10 (34%)		7 (56%)	3 (66%)
Fecal coliform	CFU/100 mL	1.1E5 (1.1)		14 (2.4)	1E4 (1.5)

[a] Performance reported as average effluent concentration with average removal in parentheses, where applicable, coliform reported as effluent concentration and log removal in parentheses.
[b] Christopherson *et al*. (2001).
[c] Crites *et al*. (1997).
[d] Louden *et al*. (1985).
[e] Jantrania (1998).

Advantages
Gravel medium (or substitute) used can be obtained in most locations. Requires less land area than comparable single-pass filters. Relatively easy to maintain and operate.

Disadvantages
Requires more electricity than single-pass systems. If appropriate medium not readily

available, cost to implement will be higher. Potential for wastewater backup in case of prolonged power outage.

Operation and maintenance
The operation of recirculating filter generally requires at least one pump and/or dosing siphon. The pump can be operated on demand or timed dosing, requiring float switches, high water alarms, and control panel. Periodic inspection of system components for proper operation is recommended. Qualitative assessment of effluent sample also confirms proper operation. Systems are generally maintenance free besides periodic inspection. Pumps and electrical components can be assumed to have at least a 10 year lifespan. Systems should be inspected regularly for ponding of wastewater on biofilter surface (or otherwise reduced infiltrative capacity) due to clogging. Correct pump and control system operation should be confirmed.

Power and control
Requires at least one pump, possibly two pumps, depending on specific site characteristics and design. Alarm and monitoring equipment recommended. Can be dosed on a timed (recommended) or on-demand basis. Annual power usage expected to be in range of 300 to 1000 kWh.

Cost
Estimated cost of multi-pass gravel biofilter system is a function of medium availability, typically $6,000 to 8,000, includes capital and installation costs of biofilter component only.

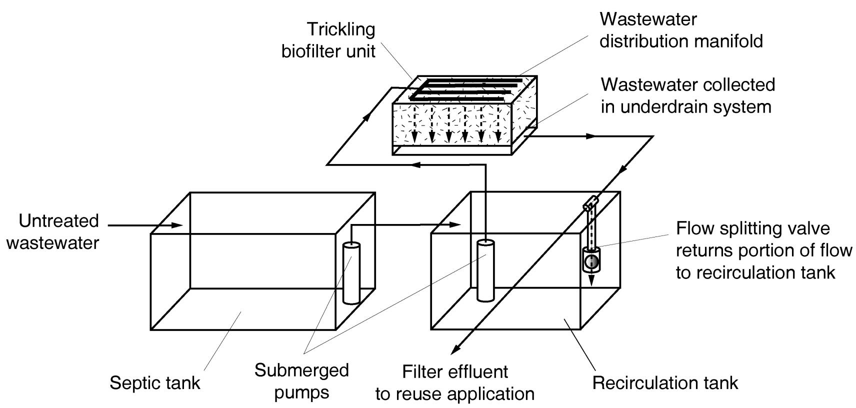

Figure 6-5
Diagram of recirculating trickling biofilter process (note: recirculation to the septic tank is also common and does not require an additional mixing tank) (top) and multi-pass gravel trickling filter installed at a residential site in Stinson Beach, CA (left).

Contact
Standard trickling biofilters systems utilizing sand medium are not proprietary and may be designed by a qualified engineer. Orenco Systems specializes in design services and provides system components.

Orenco Systems Inc.
814 Airway Avenue
Sutherlin, Oregon 97479
Phone (800) 348-9843; (541) 459-4449
Fax (541) 459-2884
Web www.orenco.com

References and other resources

Christopherson, S.H., J.L. Anderson, and D.M. Gustafson (2001) Evaluation of Recirculating Sand Filters in Minnesota, in *Proceedings of the 9th National Symposium of Individual and Small Community Sewage Systems* - 2001, Fort Worth, TX, American Society of Agricultural Engineers, pp. 207-214, St. Joseph, Michigan.

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Whitmyer, R.W., R.A. Apfel, R.J. Otis, and R.L. Meyer, (1991) Overview of Individual Onsite Nitrogen Removal Systems, On-site Wastewater treatment: *Proceedings of the 6th National*

Symposium on Individual and Small Community Systems - 1991, Chicago, Illinois, American Society of Agricultural Engineers, pp. 143-154, St. Joseph, MI.

6-1.11 PHOSPHEX™ system

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background
The Phosphex System uses a reactive media that is able to precipitate phosphorus out of water. The material evaluated in the development of the treatment system is a waste product (slag) from steel manufacturing which has a chemical composition high in metal oxides, especially calcium. The filter bed is a combination of metal oxides, limestone, and sand. This process was developed at the University of Waterloo and is not yet commercially available.

Description of process
The biofilter is located in series after a standard septic tank or other primary treatment device. Wastewater is distributed into the packed bed and allowed to percolate through for sufficient time to achieve phosphorus adsorption and precipitation. Effluent from the Phosphex system can then be discharged to an effluent management system.

System footprint
Surface area of Phosphex unit is about 75 ft^2 (estimated based on 450 gal/d of typical settled residential wastewater).

Advantages
Removes phosphorus to very low levels, may be feasible in areas that are sensitive to phosphorus loading. Expected near complete phosphorus removal from septic tank effluent.

Disadvantages
Not currently commercially available (estimate 2004).

Performance
Expect 90 to 99% phosphorus removal form septic tank effluent. Other effluent parameters not known, possibly similar to other biofilter systems.

Operation and maintenance
Operation and maintenance would include inspection of system components. If system includes electrical components, check for proper operation. Medium may need to be replaced after reaching capacity for phosphorus adsorption. Media replacement will be needed after 15 to 20 years.

Power and control
Passive process does not require the use of pumps or control system.

Cost
$2500 to 3500 (estimate), includes capital costs for installation of biofilter component only.

Contact
G.G.H Gray
E gghgray@uwaterloo.ca
Web www.research.uwaterloo.ca/ttlo/technologies/GroundWater/index.htm

References and other resources

Baker MJ, DW Blowes, and CJ Ptacek (1998) Laboratory Development of Permeable Reactive Mixtures for the Removal of Phosphorus form Onsite Wastewater Disposal Systems, *Environmental Science and Technology*, Vol. 32, No. 15, pp. 2308-2316.

U.S Patent #5,876,606.

6-1.12 RIGHT® system

Catagory	Primary and secondary treatment
Technology	Multi-pass trickling biofilter
Input	Household wastewater
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Individual home, cluster, and community residential systems

Background

The RIGHT system is a pre-assembled sand/gravel biofilter system. Because the system is preassembled, installation time is significantly reduced.

Description of process

The system is composed of two tanks, the integrated dosing tank and a biofilter unit. The integrated dosing tank is divided into three sections for primary treatment, mixing/recirculation flow, and effluent chamber. The biofilter module is divided into two sections, one section discharges to the recirculation tank and the other section discharges to the effluent tank. The recirculation of the process water allows for enhanced denitrification.

Performance

The RIGHT system performance can be estimated from the results of the Washington Island Project, as presented in Table 6-5.

Operation and maintenance

Crest Precast offers a management agreement in which the homeowner has very little responsibility except for periodic observation of the system to confirm that electrical components are still functioning properly.

Table 6-5

Reported performance results for the RIGHT systems from the Washington Island Project[a]

		System[b]				
Parameter	Unit	1	2	3	4	5
Media depth						
Fine	ft	1	2	0	1	2
Coarse	ft	1	0	2.3	1	0
HLR	$gal/ft^2 \cdot d$	5		3.4	3.5	3.7
α	unitless	4		6.8	8.1	3.8
BOD	mg/L	12 (96%)	12.4 (94%)	3.8 (98%)	10 (98.6%)	8.6 (96%)
TSS	mg/L	6 (95%)	12.6 (89%)	4.7 (97%)	5.9 (96%)	5.8 (99%)
TN	mg/L	12 (70%)	15.7 (59%)	16.8 (80%)	13.7 (89.3)	17.4 (59%)

[a] Venhuizen *et al.*, 1998

[b] Performance reported as average effluent concentration with average removal in parentheses.

Advantages
Treatment system is prepackaged and pre-engineered to reduce construction errors and reduce overall system cost.

Disadvantages
Treatment system requires electrical power for pumping and control systems.

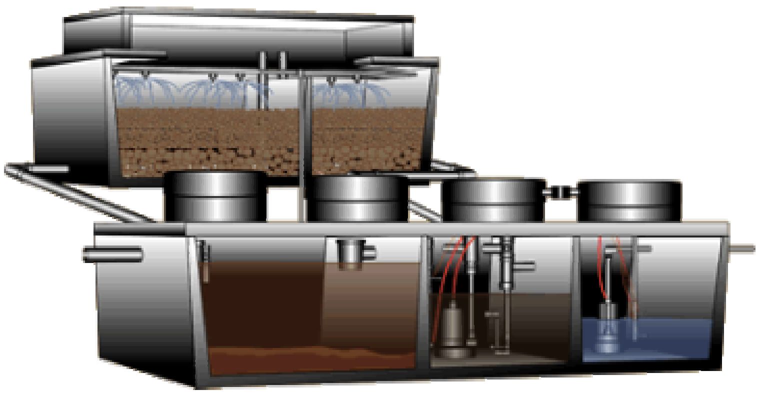

Figure 6-6
The RIGHT System for wastewater treatment. (Adapted from RIGHT System, LLC.)

Contact

Crest Precast, Inc.
609 Kistler Drive, LaCrescent, MN 55947
Phone (877) 743-4231
Web www.rightsystem.com
Description
Supplies prepackaged RIGHT System and optional drip distribution system.

The RIGHT System, LLC
P.O. Box 238
Washington Island, WI 54246
Phone (877) 843-4231
Fax (262) 843-3142
E info@RIGHTSystem.com

References and other resources

Venhuizen, D., J.H. Wiersma, and J.A. Williams (1998) Washington Island Project: Evolution of the Denitrifying Sand Filter Concept, *in Proceedings of the Eighth National Symposium on Individual and Small Community,* pp. 470-479, American Society of Agricultural Engineers, St. Joseph, MI.

6-1.13 Sand biofilters (single-pass)

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, and pathogen reduction
Applications	Single home and small community residential systems

Background
The single-pass sand filter is one of the most well-known and studied systems for the treatment of wastewater from primary treatment processes. When designed and used correctly, these systems are very reliable and provide excellent treatment. However, due to site limitations and the availability of sand medium, these systems may not be cost effective in all areas.

Description of process
Sand biofilter systems are often referred to as intermittent sand filters or single-pass sand filters. The term intermittent is a classification of the dosing regime; the water to be treated is applied to the biofilter in discrete doses, as opposed to continuous dosing. The single-pass categorization is a specification for obtaining treatment with only one application of the wastewater before discharge to subsequent treatment or use. However, the classification as a filter is somewhat misleading because the system is a biological treatment process. A diagram of the single-pass biofilter system is presented in Fig. 6-7. Sand biofilters can be operated under gravity flow or under pressure. The gravity flow system is an option when sufficient slope and land area are available for a tiered system. The pressurized configuration is more used in areas with insufficient slope and requires the use of one or two pumps.

System footprint
Typical system will have a surface area of 400 ft^2. Systems can be installed above ground, partially buried, or fully buried. Top of filter may be planted or otherwise integrated into landscape for aesthetic purposes.

Performance
Many studies have been conducted to characterize the performance and operation of single-pass sand biofilter systems. Performance specifications of representative research findings are presented in Table 6-6.

Table 6-6
Selected representative studies of single-pass sand biofilter performance

		Location of study		
Parameter	Unit	Placer Ct, CA[a]	Gloucester, MA[b]	Oregon[c]
Description of system		Compiled from 30 residential systems	Demonstration project	Compiled from 8 residential systems
ES (d_{10})	mm	0.25 to 0.65	0.8	
UC (d_{60}/d_{10})	unitless	3 to 4	1.5	
Depth of medium	ft	2	2	
HLR	$gal/ft^2 \cdot d$	1.23	86	
System performance[d]				
BOD_5	mg/L	2 (98%)	15	3.2 (99%)
TSS	mg/L	16 (78%)	8	9.6 (93%)
TN	mg/L	37 (40%)	61.3	30.3 (47%)
NO_3-N	mg/L	31	13.4	29.1
NH_3-N	mg/L	5	37.5	0.25
P	mg/L		8.3	
Total coliform	MPN/100 mL	7.3E2 (3)		1.8E4 (2)
Fecal coliform	MPN/100 mL	1.1E2 (3)	5E4	407 (3)

[a] Oregon Department of Environmental Quality (1982).
[b] Cagle and Johnson (1994).
[c] Jantrania *et al*. (1998).
[d] Performance reported as average effluent concentration with average removal in parentheses, where applicable, coliform reported as effluent concentration and log removal in parentheses.

Advantages
Design and performance is well characterized. Technology can be used in many locations when correctly sized sand media is readily available. Operation and maintenance are relatively easy.

Disadvantages
May require electricity for pump operation. For systems that rely on pumps, extended power failure can result in wastewater backup. Correctly sized media may be difficult to procure in some areas due to relative site location and/or media availability.

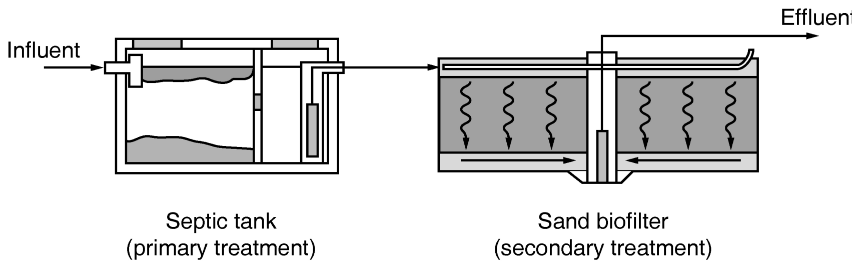

Figure 6-7
Diagram of single-pass trickling biofilter process (top) and installation of a single-pass sand trickling biofilter (left).

Operation and maintenance
Proper operation and maintenance are recommended for long-term system performance. For proper operation, specifications for hydraulic and constituent loading should be met to avoid overloading to the biofilter. Maintenance procedures should include inspection of the system for accumulation of solids and water on the surface, solids accumulation in pump basins, and other types of pump or electrical component malfunction or failure. Systems should be inspected regularly for ponding of wastewater on biofilter surface (or otherwise reduced infiltrative capacity) due to clogging. Correct pump and control system operation should be confirmed.

Power and control
Can be operated with or without pumps depending on specific site characteristics and design. Alarm and monitoring equipment recommended. Can be dosed on a timed (recommended) or on-demand basis. Annual power usage expected to range from negligible (no pump/control) to 150 kWh.

Cost
Estimated cost ranges from $3,000 to 5,000, including capital and installation costs for installation of sand biofilter component only. Range a function of cost to procure correctly sized medium, may be expensive in remote areas..

Suppliers
Standard trickling biofilters systems utilizing sand medium are not proprietary and may be

designed by a qualified engineer. Orenco Systems can provide design assistance and products for sand biofilters.

Orenco Systems Inc.
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Sutherlin, Oregon 97479
Phone (800) 348-9843; (541) 459-4449
Fax (541) 459-2884
Web www.orenco.com

References and other resources

Cagle, W.A. and L.A. Johnson (1994) Onsite Intermittent Sand Filter Systems, A Regulatory/Scientific Approach to Their Study in Placer County, California, in *Proceedings of the 7th National Symposium of Individual and Small Community Sewage Systems* - 1994, Atlanta, GA, American Society of Agricultural Engineers, pp. 283-291, St. Joseph, Michigan.

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Roynayne, M.P., R.C. Paeth, and S.A. Wilson (1982) *Final Report: Oregon Onsite Experimental Systems Program*, Oregon Department of Environmental Quality, Portland, OR.

U.S. EPA (1980) *Design Manual: Onsite Wastewater Treatment and Disposal Systems*, EPA 625-1-80-012, U. S. Environmental Protection Agency, Washington, D.C.

U.S. EPA (1999) *Wastewater Technology Fact Sheet: Intermittent Sand Filters*, EPA 932-F-99-067, United States Environmental Protection Agency, Office of Water, Washington, D.C.

6-1.14 Sand biofilters (stratified, single-pass)

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater from septic tank with effluent filter
Function	Oxidation, nutrient transformation/removal, and pathogen reduction
Applications	Single home and small community residential systems

Background

The concept of the stratified sand filter is that by gradually reducing the effective size of the sand media with depth in the biofilter, it is possible to improve overall performance. Coarse gravel layers are placed between the sand layers to allow for gas exchange and to supply oxygen to the various depths of the biofilter.

Description of process

The process is identical in operation to the single-pass sand filter. Typical loading rate of screened septic tank effluent is 1 to 1.2 gal/ft^2•d. The sand used should meet certain requirements for optimal performance. The recommended effective size and uniformity coefficient for the sand is presented in Table 6-7.

Table 6-7

Specifications for stratified sand biofilter media[a]

Parameter	Units	Top layer[b]	Middle layer[b]	Bottom layer[c]
Effective size (d_{10})	mm	1.2	0.48	0.42
Uniformity coefficient, (d_{10}/d_{60})	unitless	1.26	1.28	1.50
Depth	in	10	4	10

[a] Adapted from Washington State Department of Health (2000).
[b] Supported by a 4 in deep layer of 0.75 in diameter gravel.
[c] Supported by the gravel underdrain.

Performance

The stratified sand biofilter, as outlined in the Washington State Department of Health Guidelines, is expected to produce an effluent (when used in conjunction with a septic tank with an effluent filter) with a BOD_5 and TSS less than 10 mg/L, and have fecal coliform less than 200 MPN/100 mL. Additional performance data can be found in Table 6-8.

Table 6-8

Reported results of stratified sand biofilter performance[a]

		Location of study
Parameter	Unit	Arkansas[b]
Description of system		Pilot-scale
ES (d_{10})	mm	0.39, 0.44, and 0.16[c]
UC (d_{60}/d_{10})	unitless	3.08, 2.0, and 1.5[c]
Depth of medium	in	10, 4, and 10[c]
HLR	gal/ft^2•d	1.25
DF	dose/d	12
System performance		
BOD_5	mg/L	1.21 (99%)
Fecal coliform	CFU/100 mL	< 2 (5.8)

[a] Performance reported as average effluent concentration with average removal in parentheses, except microorganism removal, which has logs of removal reported in parentheses.
[b] Gross and Jones (1999).
[c] Values represent coarse, medium, and fine layers, respectively.

Operation and maintenance

Proper operation and maintenance are recommended for long-term system performance. For proper operation, specifications for hydraulic and constituent loading should be met to avoid overloading to the biofilter. Maintenance procedures should include inspection of the system for accumulation of solids and water on the surface, solids accumulation in pump basins, and other types of pump or electrical component malfunction or failure.

Contact

Washington State Department of Health Office of Environmental Health & Safety
New Market Industrial Center, 7171 Cleanwater Lane, Building 4
PO Box 47825
Olympia, Washington 98504-7825
Phone (360) 236-3062
Fax (360) 236-2261
Web http://www.doh.wa.gov/ehp/ts

Description

The State of Washington has developed design and performance guidelines for the stratified filter.

References and other resources

Gross, M.A. and S.W. Jones (1999) Stratified Sand Filter and Ozonation for Wastewater Reuse, in *Proceedings NOWRA Conference*, 8th Annual Conference and Exhibit, Jekyll Island, GA.

Nichols, D.J., D.C. Wolf, M.A. Gross, and E.M. Rutledge (1997) Renovation of Septic Tank Effluent in a Stratified Sand Filter, *Site Characterization and Design of Onsite Septic Systems*, ASTM STP 1324, MS Bedinger, JS Fleming, and AI Johnson, American Society for Testing and Materials, West Conshohoken, PA.

Washington State Department of Health (2000) *Stratified Sand Filter: Recommended Standards and Guidance for Performance, Application, Design, and Operation and Maintenance*, Office of Environmental Health and Safety, Olympia, WA.

6-1.15 Slag biofilters

Catagory	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, and pathogen reduction
Applications	Single home and small community residential systems

Background

Several industrial processes result in the formation of a by-product known as slag. Slag materials can be produced in blast furnaces during the production of iron or in the bottom of boilers during the coal fired electricity generation, among other places. The materials properties are dependent on the specific nature of the material and the process used during formation of the material. The specific weight of slag can range from 50 to 100 lb/ft^3 depending on the source of the material. Slag materials have been used as a biofilm support medium in trickling biofilters.

Performance

Performance specifications from representative research studies are presented in Table 6-9.

Description of process

Process similar to that of single-pass or multi-pass biofilter system. If composition of material is correct, biofilter should accomplish phosphorous removal as well as typical biofiltration treatment objectives.

System footprint
Size expected to be comparable to single-pass or multi-pass aggregate biofilter system, depending on specific configuration.

Advantages
Slag materials may be available in some locations as a waste product.

Disadvantages
Slag materials are not well established for wastewater treatment applications. Concern has been expressed regarding the leaching of constituents (e.g., metals) associated with the steel slag material into the soil. Additional research is needed to evaluate locally available slag materials for performance as well as leaching of undesirable constituents.

Operation and maintenance
Operational and maintenance needs have not been determined for this technology, however, expected to be similar to other biofilter units.

Table 6-9
Reported studies of slag trickling biofilter performance[a]

		Location of study	
Parameter	Unit	Montgomery County, VA	Montgomery County, VA
Description of system			
ES (d_{10})	mm	1.2	1.2
UC (d_{60}/d_{10})	unitless	1.67	1.67
Depth of medium	ft	2	2
α	unitless	27	23
HLR	gal/ft^2•d	2.5	5.6
DF	dose/d	48	68
pH	unitless	7.3	7.2
System performance[b]			
BOD_5	mg/L	4.9 (95%)	2 (98%)
NO_3-N	mg/L	39.6	43
NH_3-N	mg/L	0.4	0.2
P	mg/L	8.1 (10%)	6.1 (5%)
Fecal coliform	CFU/100 mL	22 (3.1)	145

[a] Reneau *et al.* (1998).
[b] Performance reported as average effluent concentration with average removal in parentheses, except microorganism removal, which has logs of removal reported in parentheses.

Contact
National Slag Association
Web www.nationalslagassoc.org

References and other resources

Reneau Jr., R.B., C. Hagedorn, and A.R. Jantrania (2001) Performance Evaluation of Two Pre-Engineered Onsite Treatment and Effluent Dispersal Technologies, in *Proceedings of the 9th National Symposium of Individual and Small Community Sewage Systems* - 2001, Fort Worth, TX, American Society of Agricultural Engineers, pp. 271-280, St. Joseph, Michigan.

6-1.16 Zeolite biofilter

Category	Cation exchange, removal
Technology	Trickling biofilter, adsorption
Input	Settled wastewater, septic tank effluent
Function	Ion exchange, nutrient removal
Applications	Various

Background

Zeolites are negatively charged minerals, similar in structure to clay. The zeolite structure is three dimensional, and creates an open, cage-like matrix, which is effective for ion exchange processes. Ammonia and heavy metals in wastewater are readily adsorbed onto the zeolite structure.

Description of process

While not common for onsite wastewater treatment processes, zeolites offer the advantage of removing ammonia nitrogen and other positively charged ions from wastewater. This type of system may be useful in areas that are sensitive to nitrogen discharges. The zeolite material may be used in a packed bed arrangement or as a fill material in soil treatment systems.

Performance

Zeolites are effective ion exchange materials and can be expected to remove a significant amount of positively charged ions. The adsorption capacity of natural zeolites is typically in the range of 1 to 6 mg metal/g zeolite and 1 to 2 mg ammonia/g zeolite. Synthetic zeolites generally have a higher adsorptive capacity. The removal efficiency also depends on the selectivity of the constituent to be removed and the pH of the wastewater.

Operation and maintenance

Because the zeolites acts as an ion exchange resin, it will need to be regenerated periodically as it reaches the exchange capacity.

Cost

Suppliers of zeolite should be contacted directly to determine cost of material. Construction costs can be estimated from cost to install single-pass sand biofilter. The zeolite regeneration may be a significant cost.

References

Ouki, S.K. and M Kavannagh (1999) Treatment of metals-contaminated water by use of natural zeolites, *Water Science and Technology*, Vol. 39, No. 10-11.

Contact

International Zeolite Association	Zeoponix
Web www.iza-online.org	Web www.zeoponix.com

6-2 Organic media trickling biofilters

The use of organic materials as the support medium in the trickling biofilter may have advantages over other types of media, including the potential for enhanced nutrient removal, a lightweight material, and potentially locally available. Peat moss has been the primary organic material used as a biofiltration medium.

6-2.1 Ecoflo® biofilter

Catagory	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background
The Ecoflo biofilter (ST-650) system developed by Premier Tech uses sphagnum peat moss as the medium for the attached growth of a microbial community. The technology is compact and modular, allowing for flexibility in installation.

Description of process
The process does not use any electrical components and influent to the biofilter is settled wastewater from a septic tank or similar device. Wastewater is distributed over the surface of a treated peat medium. After passing through the treatment process, the effluent can be directly discharged into the soil through the bottomless filter or collected and discharged to an alternate effluent management system. In addition, the Ecoflo technology has been used for the polishing treatment of secondary treated wastewater and landfill leachate. The basic Ecoflo unit is bottomless allowing effluent to discharge into soil below. Effluent management will depend on characteristics of the receiving location. Effluent may be distributed through drip irrigation (after disinfection) or other soil treatment system.

System footprint
Ecoflo module has a length of 14 ft, width of 8 ft, height of 4.5 ft, and weight of 275 lbs. Systems normally buried below grade, but can be installed above ground or partially buried.

Advantages
Modular system offers flexible installation. Bottomless filter does not require additional system for effluent distribution. Potential for passive operation.

Disadvantages
May require electricity for pump operation. Somewhat limited performance data available. Biofilter medium will need to be replaced periodically. If overloaded, system may pond.

Performance
Expected effluent quality for BOD_5 and TSS concentrations less than 10 mg/L, and fecal coliforms less than 25,000 MPN/100 mL (as verified by Environmental Technology Verification (ETV) Canada). Nitrogen and phosphorus removal data not available at this time.

Operation and maintenance
System based on single-pass operation and does not require a pump if site conditions permit gravity flow. Peat filtration material expected to last maximum of 7 to 8 years under normal use, after this time will need to be replaced. Manufacturer recommends annual inspection and upkeep. Systems should be inspected annually if passive system. If pump and control system is used, should be inspected more frequently.

Power and control
Pump and control system is not part of basic unit, but can be used if needed. With pump, expected annual power usage 50 to 150 kWh.

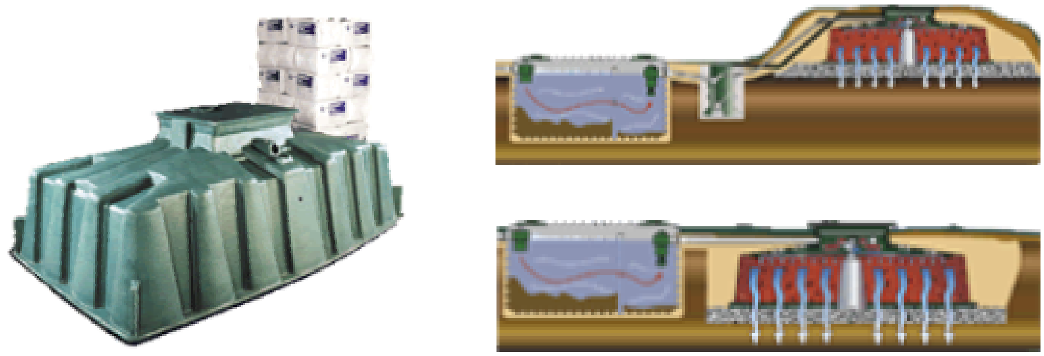


Figure 6-8
A photo of the Ecoflo biofilter wastewater treatment unit (left) and diagrams showing bottomless Ecoflo biofilter system in pressure dosed configuration (right top) and gravity flow configuration (right bottom). (Adapted from Premier Tech Environment.)

Cost
Estimated cost range from $4,000 to 5,000 which includes capital costs for biofilter component only. The range is a function of open bottom design or closed bottom design (for remote soil treatment).

Contact
Premier Tech Environment
6021 Terrace Hills Dr
Birmingham, AL 35242
Phone (205) 408-9691; (877) 295-5763
Fax (205) 408-8783
E ecoflo@premiertech.com
Web www.premiertech.com
Model description
Basic unit is the ST-650 for treating wastewater for households up to 10 bedrooms. The biofilter is available with or without a bottom collection pan. Units can be assembled in parallel to treat high flow rates, such as for cluster systems.
Manufacturer support
A seven year service contract is included in the purchase price. After seven years, peat media is replaced and service contract is renewed.

References and other resources
Lacasse, R., G. Belanger, Y. Henry, P. Talbot, J. Mlynarek, and O. Vermeersch (2001) A Denitrification Process Based on a New Filtering Media for Onsite Wastewater Treatment, *Proccedings of the Ninth National Symposium on Individual and Small Community Sewage Systems*, American Society of Agricultural Engineers, pp. 235-244, St. Joseph, MI.

U.S. EPA (2001) *CEIT Virtual Trade Show: Ecoflo Biofilter (available at www.epa.gov/region1/steward/ceitts/wastewater/techs/ecoflo.html).*

6-2.2 ECO-PURE® peat biofilter

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background
The ECO-PURE peat biofilter is a modular wastewater treatment unit housed in a watertight polyethylene tank. The tank is equipped with anti-float baffles for areas with high ground water conditions. The ECO-PURE systems are in use in most eastern states.

Description of process
Primary treated wastewater (septic tank effluent) is dispersed on the surface of the peat biofilter and is treated as it moves through the biofilter. Effluent is collected and dispersed with a drip irrigation system.

Performance
Manufacturer claims system performance of BOD_5 and TSS less than 10 mg/L in effluent. Fecal coliform also significantly reduced, effluent concentrations often less than 200 MPN/100 mL.

Operation and maintenance
Maintenance is performed by manufacturer or service representative under service contract. Periodic inspection to confirm that system is operating properly. Replacement of peat material may be needed after about 10 years.

Power and control
Pump and control system not part of basic unit, but can be used if needed. With pump, expected annual power usage is about 1,000 to 2,000 kWh.

Cost
$2,000 to 3,000, includes capital costs for biofilter component only.

Suppliers / contacts
ECO-PURE Waste Water Systems
17305 Pine Ridge Road
Fort Meyers, FL 33931
Phone (888) 999-0936
Fax (888) 999-5259
Model description

Eco-pure 300 series (450 gal/d, 600 gal/d max surge capacity)

Manufacturer support

Five year maintenance contract included with purchase price. After five years, new service contract is required. Manufacturer warrants Eco-pure components for 3 years from date of purchase.

6-2.3 Peat moss trickling biofilters

Catagory	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, and pathogen reduction
Applications	Single home and small community residential systems

Background
Peat used for wastewater treatment is generally the harvested and dried sphagnum moss plant that grows across Canada and in some parts of the United States. Peat as a biofilter medium has been researched in the United States since the 1970s. Much of the initial research on using peat as an onsite biofilter material was performed by Dr. Joan Brooks of the University of Maine (see references).

Description of process
Can be operated in single-pass or multi-pass configurations, similar to standard sand and gravel biofilters. Primary effluent is sprayed onto the surface of the peat biofilter. Wastewater constituents are removed through adsorption into the attached microbial community which inhabits the peat material. The peat is often supported above a standard gravel collection system. The properties of peat that are believed to contribute to its high performance include acidic nature of the material, support of fungal communities, high cation exchange capacity, high surface area, and other antibiotic properties.

Advantages
Medium is a natural, lightweight, high porosity material. In many research studies, peat has been an effective biofilter material, particularly for the removal of fecal coliform. Potential for long term reliable treatment with relatively low maintenance requirements.

Disadvantages
May require electricity for pump operation. Peat must be imported from northern areas where it is harvested. If overloaded, system may pond.

Performance
Performance specifications from representative research studies are presented in Table 6-10.

Table 6-10
Selected representative studies of peat moss biofilter performance[a]

		Location of study[b]		
Parameter	Unit	Maine	Maine	Maine
Description of system		Residential	Residential	Residential
Depth of medium	ft	2.5 to 3	2.5 to 3	1 to 3
HLR	gal/ft^2•d	0.4	0.18	0.8
DF	dose/d	On demand	On demand	On demand
Temp	^{o}F	36 to 57	37 to 68	
pH	unitless	5.4 tp 6.4	5.8 to 6.5	5.3 to 6.4
System performance				
COD	mg/L	82 (86%)	108 (82%)	121 (84%)
BOD_5	mg/L	15 (94%)	14 (94%)	24 (91%)
TSS	mg/L	16 (90%)	9 (88%)	
TN	mg/L	8.1 (83%)	16.7 (76%)	20.3 (69%)
NO_3-N	mg/L	4.2	4.4	0.3
NH_3-N	mg/L	2.4	10.4	17.7
P	mg/L	3.2 (58%)	14.9 (62%)	0.5 (96%)
Fecal coliform	CFU/100 mL	< 1 (6.8)	16 (6.4)	

[a] Brooks *et al.*, 1984.
[b] Performance reported as average effluent concentration with average removal in parentheses, except microorganism removal, which has logs of removal reported in parentheses.

System footprint
Typical system will have a surface area of 250 to 400 ft^2. Systems can be installed above

ground, partially buried, or fully buried. Top of filter may be planted or otherwise integrated into landscape for aesthetic purposes.

Operation and maintenance
Operation and maintenance needs are similar to other biofilter systems, including pumping of solids from the septic tank as needed, cleaning of any effluent filter used, inspection of pumps and other control and monitoring devices. In addition, the peat material used may decompose over time, especially in hot climates. In the case of peat decomposition, the material should be removed and replaced with new peat material. Systems should be inspected regularly for correct pump and control system operation. Pumping of septic tank and cleaning of septic tank effluent filter are also needed.

Power and control
Can be operated with or without pumps depending on specific site characteristics and design. Alarm and monitoring equipment recommended. Can be dosed on a timed (recommended) or on-demand basis. Annual power usage expected to range from negligible (no pump/control) to 50 to 150 kWh.

Cost
Estimated cost range ranges from $3,000 to 5,000, including capital and installation costs for biofilter component only

Figure 6-9

A Natural peat bog in Canada

Contact
Peat used in treatment systems is typically proprietary, however, may be available from nurseries or landscape supply outlets. Peat from different regions and the quality of the peat used may affect overall treatment performance. Prefabricated and engineered peat treatment systems are currently available.

References and other resources
Brooks, J.L. (1980) *A field study of the efficiency of sphagnum peat as a medium for the treatment of residential wastewater*. M. S. Thesis. (unpublished). University of Maine, Orono, ME.

Brooks, J.L., C.A. Rock, and R.A. Struchtemeyer (1984) Use of peat for on-site wastewater treatment: II. Field studies. *Journal of Environmental Quality*, Vol. 15, pp. 524-530.

Brooks, J.L., and J.A. McKee (1992) Application of peat on-site wastewater treatment systems in the Ontario environment, *Conference Proceedings of Alternative Septic Systems for Ontario,* Waterloo Centre for Groundwater Research, University of Waterloo, pp. 23-30.

Canadian Sphagnum Peat Moss Association <www.peatmoss.com>.

Couillard, D. (1994) The use of peat in wastewater treatment, *Water Resources*, Vol. 26, pp. 1261-1274.

Coupal, B., and J. Lalancette (1976) The treatment of wastewaters with peat moss, *Water Research*, Vol. 10, p. 1071.

Farnham, R.S., and J.L. Brown (1972) Advanced wastewater treatment using organic and inorganic materials. Part I. Use of peat and peat-sand filtration medias. *Proceedings of the 4th International Peat Congress*, International Peat Society, pp. 271-286, Helsiniki, Finland.

Lindbo, D.L., and V.L. MacConnell (2001) Evaluation of a Peat Biofilter Treatment System, in Onsite Wastewater Treatment, *Proceedings of the Ninth National Symposium on Individiual and Small Community Sewage Systems*, Fort Worth, TX, American Society of Agricultural Engineers, pp. 225-234, St. Joseph, MI.

McKee, J.A., and J.L. Brooks (1994) Peat filters for on-site wastewater treatment. *Proceedings of the Seventh National Symposium on Onsite Wastewater Treatment Systems*, American Society of Agricultural Engineers, pp. 526-541, St. Joseph, MI.

Nichols, D.S., and D.H. Boelter (1982) Treatment of secondary sewage effluent with a peatsand filter bed, Journal of Environmental Quality, Vol. 11, pp. 86-92.

O'Driscoll, J.P., K.D. White, D.W. Salter, and L. Garner (1998) Long term performance of peat biofilters for onsite wastewater treatment. *Proceedings of the Eighth National Symposium on Onsite Wastewater Treatment Systems*, American Society of Agricultural Engineers, pp. 530-537, St. Joseph, MI.

Rana, S.M., and T. Viraraghaven (1987) Use of peat in septic tank effluent treatment-column studies, *Water Pollution Research Journal of Canada*, Vol. 22, pp. 491-504.

Rock, C.A., J.L. Brooks, S.A. Braden, and R.A. Struchtemeyer (1984) Use of peat for on-site waste water treatment: I. Laboratory evaluation, *Journal of Environmental Quality*, Vol. 13, pp. 518-523.

Talbot, P., G. Belanger, M. Pelletier, G. Laliberte, and Y. Arcand (1996) Development of a biofilter using organic medium for on-site wastewater treatment. *Water Science and Technology*, Vol. 34, pp. 435-441.

Talbot, P., H. Ouellett, and G. Laliberte (1998) Development of a new on-site wastewater treatment technology in the evolving context of the last decade, *Proceedings of the Eighth National Symposium on Onsite Wastewater Treatment Systems*, American Society of Agricultural Engineers, pp. 538-544, St. Joseph, MI.

Viraraghaven, T., and S.M. Rana (1991) Use of adsorption models for the design of peat based on-site systems, *Proceedings of the Eighth National Symposium on Onsite Wastewater Treatment Systems*, American Society of Agricultural Engineers, pp. 165-172, St. Joseph, MI.

Winkler, E.S., and P.L.M. Veneman (1991) A denitrification system for septic tank effluent using sphagnum peat moss. *Proceedings of the Eighth National Symposium on Onsite Wastewater Treatment Systems*, American Society of Agricultural Engineers, pp. 155-164, St. Joseph, MI.

6-2.4 Puraflo® peat biofilter

Catagory	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background
The Puraflo peat biofilter is a modular treatment system generally composed of a septic tank fitted with an effluent filter, a pump or recirculation tank, modular peat biofilter units, and a soil treatment/adsorption field.

Description of process
The Puraflo biofiltration system is similar to other single-pass systems. Effluent from a septic tank (typically with an effluent filter) is distributed over the surface of the peat media. After passing through the biofilter, the water is collected in a collection system and discharged to a soil adsorption system.

Performance
Puraflo peat biofilters have been effective for the treatment of wastewater in both single-pass and multi-pass configurations. Additional performance specifications from representative research studies are presented in Table 6-11.

Table 6-11
Selected representative studies of Puraflo peat biofilter performance

		Location of study			
Parameter	Unit	Minnesota[a]	Minnesota[a]	Maryland[b]	Maryland[b]
Description of system		Residential, single-pass	Residential multi-pass	Demonstration, single-pass	Demonstration, multi-pass
HLR	gal/d	285	175		
System performance[c]					
BOD_5	mg/L	4,5 (98%)	9 (97%)	4.5 (97%)	2.2 (98%)
TSS	mg/L	2.5 (96%)	3.3 (94%)	10.1 (85%)	13 (88%)
TN	mg/L	66 (29%)	51 (43%)	36 (31%)	26 (56%)
NO_3-N	mg/L	43	33		
NH_3-N	mg/L	25	19		
P	mg/L	14 (14%)	12 (19%)		
Fecal coliform	CFU/100 mL	2E3 (2.5)	2E2 (3.4)	2E3 (1.6)	4E2 (3.2)

[a] Anne Arundel County National Onsite Demonstration Project
[b] Geerts *et al.*, 2001
[c] Performance reported as average effluent concentration with average removal in parentheses, except microorganism removal, which has logs of removal reported in parentheses.

System footprint
Typical system composed of three modular units, with a length of 7 ft, width of 4.6 ft, and depth of 2.5 ft (total surface area of biofilter units is 100 ft^2). Systems can be installed above ground, partially buried, or fully buried.

Advantages
Well documented performance. Modular system installation is adaptable to site conditions. Treatment system is effective and has low space requirements.

Disadvantages
May require electricity for pump operation. If overloaded, system may pond. Peat medium will need to be replaced periodically.

Operation and maintenance
Periodic inspection for proper operation. Peat media may need to be replaced after 8 to 15 years (cost approximately $500 per module). Correct pump and control system operation should be confirmed.

Power and control
System includes septic tank effluent pump, alarm, and control equipment. Annual power usage expected to be 150 to 1000 kWh, for single-pass and multi-pass configurations, respectively.

Cost
Estimated cost of $5,000 to 6,000, includes capital costs for biofilter modules, electrical supplies, effluent filter, piping, and valves.

Figure 6-10
Installation of Puraflo peat biofilter system (left), and completed installation (right). (Adapted from Bord na Móna Environmental, Inc.)

Contact
Bord na Móna Environmental
P.O. BOX 77457
Greensboro, NC 27417
Phone (336) 547-9338
1-800-PURAFLO (787-2356)
FAX (336) 547-8559
E bnm-us@bnm-us.com
Web www.bnm-us.com
Model description
Each Puraflo module is rated for 125 gal/d for typical residential wastewater.
Manufacturer support
Two year guarantee on treatment system, associated service contract not determined.

References and other resources
Geerts, S.D., B. McCarthy, R. Axler, J. Henneck, S. Heger Christopherson, J. Crosby, and M. Guite (2001) Performance of Peat Filters in the Treatment of Domestic Wastewater in

Minnesota, in *Proceedings of the 9th National Symposium of Individual and Small Community Sewage Systems* - 2001, Fort Worth, TX, American Society of Agricultural Engineers, pp. 295-303, St. Joseph, MI.

O'Driscoll, J.P., K.D. White, D.W. Salter, and L. Garner (1998) Long Term Performance of Peat Biofilters of Onsite Wastewater Treatment, in *Proceedings of the 8th National Symposium of Individual and Small Community Sewage Systems* - 1998, and Orlando, FL, American Society of Agricultural Engineers, pp. 530-537, St. Joseph, MI.

Walsh, J., and H. Henry (1997) Performance of the Puraflo Peat Biofilter Using Selected Peat FIbre, *Proceeding of the Waterloo Center for Groundwater Research Conference on Septic Odour, Commercial Wastewater, and Phosphorus Removal.*

6-2.5 Woodchip trickling biofilters

Catagory	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background
The use of woodchips as a biofilter material is not well documented in the literature; however, it is feasible that this material will be evaluated for its potential as a biofilter medium in the future. In addition, wood chips of various sizes are available for free or at low cost.

Contact
Woodchips and other wood by-products may be obtained locally as a waste material.

6-3 Synthetic media trickling biofilters

The use of synthetic materials, including foam and geotextile, for use as biofiltration media offers several advantages over other materials. These materials are lightweight, have a high porosity and surface area, and are resistant to surface clogging. This combination of material properties makes it possible to apply higher loading, when compared with granular materials, resulting in a significantly smaller overall system footprint.

6-3.1 Advantex® trickling biofilters

Catagory	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single, cluster, and community residential systems, commercial applications

Background
The Advantex filter is a high porosity attached growth treatment system manufactured by Orenco Systems Inc. The Advantex unit is relatively small, lightweight, and provides effective treatment of septic tank effluent. Loading rates are typically 15 to 30 times higher than for fine sand biofilter devices.

Description of process
Primary treated water (septic tank effluent) is distributed to the surface of the filter and flows by gravity over the fixed film media. Because the media has a high porosity, clogging is not expected, as with sand biofilters. After passing through the medium, the treated water is

collected and a fraction is discharged and the remainder is returned to the first chamber of the septic tank for denitrification.

System footprint
Typical system will have a surface area of 10 to 32 ft^2 (length of 8 ft, width of 4 ft, and height of 2.5 ft). Systems can be installed above ground, partially buried, or fully buried. In many cases, system can be installed directly above the septic tank.

Advantages
Treatment unit has small footprint and modular design, typically installed flush with the ground. Excellent and stable performance under fluctuating loading. Lightweight and efficient pre-packaged units. Potential for high nitrogen removal. High porosity media not likely to clog, serviceable without replacement of media. Low maintenance requirements.

Disadvantages
Fecal coliform removal is inconsistent. Requires electricity for proper operation.

Performance
The Advantex system has been found to provide effective, stable treatment of septic tank effluent, frequently under 10 mg/L of BOD_5 and TSS. Additional performance specifications from representative research studies are presented in Table 6-12. The Advantex treatment systems performance has also been NSF standard 40 certified for class 1 treatment.

Table 6-12
Selected representative studies of Advantex performance

		Location of study			
Parameter	Unit	La Pine, OR[b]	Roseburg, OR[c]	La Pine, OR[d]	NSF[e]
Description of system		Residential	Country Store	Residential	
HLR	gal/d	340	411		500
DF	dose/d	72			
System performance[a]					
BOD_5	mg/L	9.2	5 (98%)	11.4	5
TSS	mg/L	4.6	3 (90%)	8.7	4
Oil/grease	mg/L			3	
TN	mg/L	7.1	7 (78%)	15	13
NO_3-N	mg/L	3.1	2.9	8.5	
NH_3-N	mg/L	2.3	1	0.8	
P	mg/L			9.3	
Fecal coliform	CFU/100 mL			2E5	

[a] Performance reported as average effluent concentration with average removal in parentheses, except microorganism removal, which has logs of removal reported in parentheses.
[b] Results reported first year of performance on system after startup, RX30 effluent recycled to septic tank (Orenco Systems Inc., 2001).
[c] Bounds *et al*. (2000).
[d] Estimated from La Pine National Onsite Demonstration Project Results.
[e] NSF Standard 40.

Operation and maintenance

The Advantex treatment system pumps are generally operated on a timed dosing basis using logic controllers to set the dosing regime. The pumps, control panel, and float alarms will need periodic inspection to ensure that they are working to design specifications. The septic tank will require periodic pumping and if an effluent filter is present, it will also need a periodic cleaning. System should be inspected periodically to ensure all components are working. Sludge removal from septic tank. Remote monitoring reduces owner responsibility.

Power and control

Operate with one or two pumps depending on specific site requirements. Control panel and alarm systems standard. Telemetric monitoring optional. Estimated annual power usage 500 to 1,000 kWh.

Cost

Estimated cost ranges from $3,000 to 5,000, including capital costs for Advantex unit, pumps, and controls. Contact Orenco for local dealers and more specific cost information.

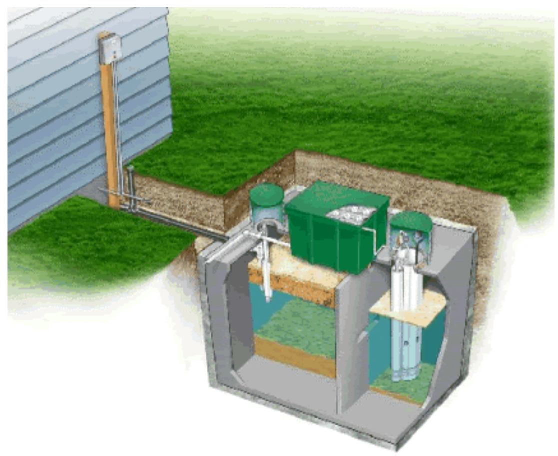


Figure 6-11

Orenco Advantex wastewater treatment systems under evaluation at University of California, Davis (top left), installed at a residential location (bottom left), and a diagram of the system installed with a septic tank (right). (Adapted from Orenco Systems, Inc.)

Contact

Orenco Systems Inc.
814 Airway Avenue
Sutherlin, Oregon 97479
Phone   (800) 348-9843; (541) 459-4449
Fax   (541) 459-2884
Web   www.orenco.com
Model Description
    AX15 (400 gal/d, 800 gal/d peak)
    AX20 (500 gal/d, 1000 gal/d peak)
    AX100
Manufacturer support
    Three year limited warranty on treatment system, authorized service providers.

References and other resources

Bounds, T., E.S. Ball, and H.L. Ball (2000) Performance of Pakced Bed Filters, in *Proceedings of the National Onsite Wastewater Recycling Association Conference*, Jekyll Island, GA.

Orenco Systems Inc. (2001) La Pine, Oregon Demonstration Site

Leverenz, H., L. Ruppe, G. Tchobanoglous, and J. Darby (2001) Evaluation of High-porosity Medium in Intermittently Dosed, Multi-Pass Packed Bed Filters for the Treatment of Wastewater, *Small Flows Quarterly*, Spring 2001, Vol. 2, No.2.

Roy, C., R. Auger, and R. Chenier (1998) Use of Non-woven Fabric in Intermittent Filters, in *Proceeding of the Eight National Symposium on Individual and Small Community Sewage Systems, Orlando, FL,* American Society of Agricultural Engineering, St Joseph, MI.

US Patents 5,531,894; 5,480,561; 5,492,635; and 4,439,323.

6-3.2 Aerocell™ treatment system

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background

The Aerocell treatment system uses the Waterloo biofilter open-cell foam technology adapted to the Zabel line of products.

Description of process

The treatment systems are composed of several modular units that can be configured to suit specific site requirements. The Aerocell treatment system is generally operated in a multi-pass mode, and consists of 4 to 6 modules for a 3 to 4 bedroom home, respectively. Wastewater is distributed over the surface of the biofilter with a spray nozzle and collected in the bottom of the units for return to the septic tank (for denitrification) or to subsequent treatment (e.g., soil adsorption).

System footprint

Typical system will have a surface area of 25 ft^2. Dimensions of modular unit are 2.2 ft in diameter and 3.2 ft in height, and each weighing about 25 lbs (total surface area for 4 unit system is 15 ft^2. A typical home system will require 4 to 6 of these units.

Advantages

Modular treatment system offers flexibility of installation. Units come preassembled, reducing installation time. Lightweight and movable by one person.

Disadvantages

Requires electricity for pump operation. Somewhat limited performance data available. For systems that rely on pumps, extended power failure can result in wastewater backup.

Performance

Manufacturer performance claims of BOD_5 less than 25 mg/L, TSS less than 30 mg/L, and 20 to 60 percent total nitrogen removal. Treatment performance is expected to be similar to that achieved by the Waterloo Biofilter (see Sec. 6-3.7).

Operation and maintenance
Basic operation and maintenance consists of regular inspection and cleaning of the spray nozzle, control panel, pumps, and other system components as needed. Maintenance includes checking system components for proper operation, and settings for electrical devices. Removal of sludge from septic tank and periodic cleaning of spray nozzles may be necessary.

Power and control
Recirculating systems will require a pump. Other components include control panel, float switches, and alarm device. Estimated annual power usage 500 to 1,000 kWh.

Cost
$3,000 to 4,500, includes capital costs biofilter and associated pump, control panel, effluent filter, and distribution components.

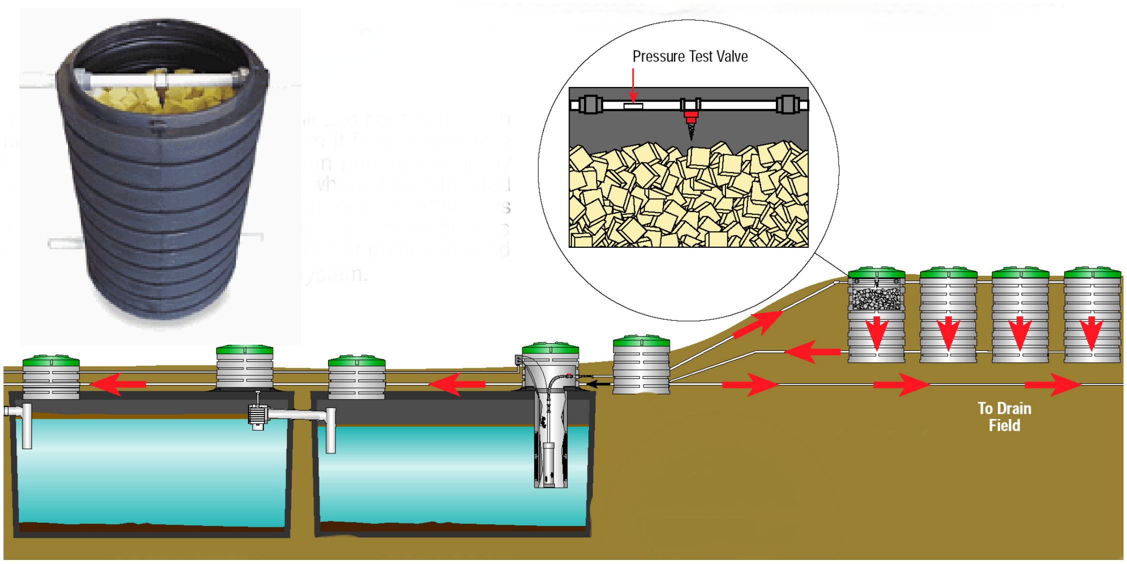


Figure 6-12

Aerocell treatment system with primary treatment, distribution tank, and modular treatment units. (Adapted from Zabel Environmental Technology, Inc.)

Contact
Zabel Environmental Technology
PO Box 1520
Crestwood, KY 40014
Phone   (502) 992-8200
            (800) 221-5742
Fax   (502) 992-8201
Web   www.zabelzone.com
Model Description
            ATS AC 3 (450 gal/d)
            ATS AC 4 (600 gal/d)
Manufacturer support
            Not determined

References and other resources
Aerocell product brochure (2002) Zabel Environmental Technologies.

6-3.3 Bioclere™ trickling biofilters

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home, small community, commercial, institutional

Background
The Bioclere modular wastewater treatment system is a modified trickling filter placed over a clarifier. The system is adaptable to larger flow rates by placing units in parallel. The Bioclere wastewater treatment system has been certified under NSF Standard 40 as producing a Class 1 effluent. The Bioclere RF (roughing filter) is an alternate design for reducing concentrated wastewater (high strength) to residential concentrations. Applications for this type of process include malls, institutions, restaurants, and other facilities.

Description of process
Wastewater from the septic tank flows into the 500 gal baffled clarifier of the Bioclere unit. A pump suspended in the upper section of the clarifier doses the fixed film process using a splash plate or spray distribution system. Sloughed biomass and the treated wastewater are returned to the clarifier. A pump at the bottom of the clarifier periodically returns settled material to the septic tank to enhance nitrogen removal. A fan is also incorporated to provide sufficient aeration to the fixed film process. The medium used in the Bioclere process is a randomly packed, high porosity plastic that has a high surface area for microbial attachment.

System footprint
Typical residential system will have a surface area of 20 ft^2 (diameter of 5 ft, depth of 9 ft) not including septic system and effluent management components. Systems normally installed partially buried for ease of maintenance.

Advantages
Modular preassembled unit increases efficiency of installation and flexibility of installation. Effective and stable treatment process, high removal of oil and grease from wastewater. NSF approved, Standard 40, Class1. Contained in a sealed and insulated container to buffer temperatures and reduce noise output.

Disadvantages
Require electricity for pump and fan operation. Requires additional processes for high degrees of nitrogen and phosphorus removal.

Operation and maintenance
The Bioclere system utilizes several electrical and mechanical components which will require periodic servicing. The basic process utilizes two pumps and a fan. Regular inspection is recommended to ensure process is operating as designed. Systems only sold to qualified management districts to ensure operation and maintenance activity. Pumps, fan, and system components should be checked regularly.

Performance
The Bioclere effluent concentrations for BOD_5 and TSS are expected to be less than 20 mg/L. The Bioclere RF is designed to reduce wastewater with BOD_5 and TSS greater than 1,000 mg/L to typical residential strength. Additional performance specifications from representative research studies are presented in Table 6-13.

Table 6-13
Selected representative studies of Bioclere trickling biofilter performance

		Location of study	
Parameter	Unit	Gloucester, MA[a]	Gloucester, MA[b]
Description of system		Residential	Residential
System performance[c]			
BOD_5	mg/L	29 (80%)	51 (79%)
TSS	mg/L	33 (31%)	42 (93%)
Oil/grease	mg/L	2.7 (95%)	4.8 (90%)
TN	mg/L	26.7 (32%)	29.2 (63%)
NO_3-N	mg/L	12.8	7
NH_3-N	mg/L	7.6	14.2
P	mg/L	6.4 (15%)	4.8 (52%)
Fecal coliform	CFU/100 mL	7.0E3 (1.5)	1.0E5 (1)

[a] Five bedroom residential site, average of 3 to 4 years of data.
[b] Four bedroom residential site, average of 3 to 4 years of data.
[c] Performance reported as average effluent concentration with average removal in parentheses, except microorganism removal, which has logs of removal reported in parentheses.

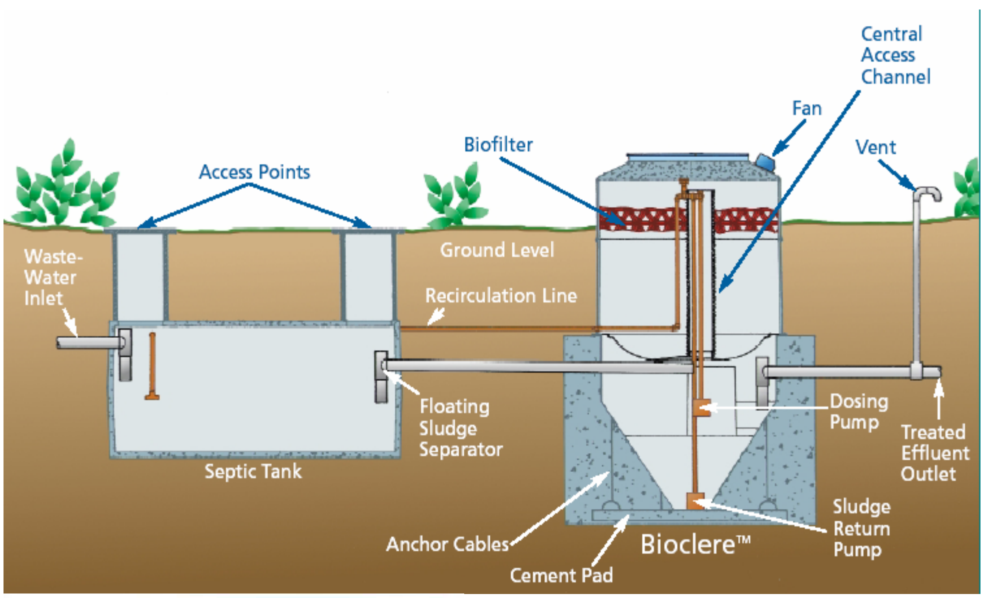


Figure 6-13
A diagram of the Bioclere wastewater treatment system (top) and installed (left). (Adapted from Aquapoint, Inc.)

Power and control
Power requirements include two pumps and a fan. Annual power usage expected to range from 1,000 to 2,000 kWh.

Cost
Estimated cost from $3,000 to 4,000 (for Bioclere unit only), cost reduced when used for the treatment of wastewater from housing clusters. Contact manufacturer for more detailed cost information.

Contact
The Bioclere unit and several other patented wastewater treatment systems are manufactured by AWT Environmental Inc. Other systems provided by this manufacturer include units for nitrogen and phosphorus removal and roughing filters for reducing concentrated wastewaters to residential wastewater concentrations.

Aquapoint / AWT Environmental, Inc.
241 Duchaine Blvd.
New Bedford, MA 02745
Phone (508) 998-7577
Fax (508) 998-7177
E awt@aquapoint.com
Web www.bioclere.com
Model descriptions
- Bioclere Model 16/12 (500 to 1000 gal/d)
- Bioclere other models (systems for flow rates of 1,000 to 150,000 gal/d)
- Bioclere RF (for BOD and TSS greater than 1000 mg/L)

Manufacturer support
- Recommended semi-annual or quarterly inspection. Expected 2 year service agreement as specified under NSF certification. Units only sold to qualified management districts to ensure operation and maintenance.

References and other resources
Aquapoint company literature (2002), available at www.bioclere.com.

Jantrania, A.R., K.C. Sheu, A.N. Cooperman, and O.C. Pancorbo (1998) Performance Evaluation of Alternative Systems – Gloucester, MA, Demonstration Project, in *Proceedings of the Eight National Symposium on Individual and Small Community Sewage Systems,* Orlando, FL, American Society of Agricultural Engineering, St Joseph, MI.

6-3.4 Rubber (shredded tire) biofilter

Category	Secondary treatment, soil treatment system
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Substitute for aggregate fill in various applications

Background
Work to find markets for waste materials has resulted in some products being evaluated for various types of fill projects. Shredded tires and crushed glass are both materials collected in solid waste management systems. However, for shredded tires there may be concern over leaching of metals and other carcinogenic and non-carcinogenic organic compounds.

Description of process
Tires are known to leach organic and inorganic constituents such as iron, manganese,

aluminum, chromium, copper, zinc, chloride, and sulfate. The concentration of these constituents in the leachate has been found to be below drinking water standards (Sengupta and Miller, 1999).

Performance
Shredded tires have not been evaluated for performance as trickling biofilter medium.

References and other resources
Burnell, B.N., and G. McOmber (1997) Used Tires as a Substitute for Drainfield Aggregate, *ASTM STP 1324*, American Society for Testing Materials.

Sengupta, S., and H.J. Miller (1999) Preliminary Investigation of Tire Shreds for Use in Residential Subsurface Leaching Field Systems, *Chelsea Center for Recycling and Economic Development Technical Research Program,* University of Massachusetts, Lowell, MA.

6-3.5 SCAT™ treatment system

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Single home and small community residential systems

Background
The SCAT treatment system uses the Waterloo Biofilter open-cell foam technology adapted to the Zabel line of products.

Cost
$2,000 to $4,500, includes capital costs of the biofilter and associated pump, control panel, effluent filter, and distribution components.

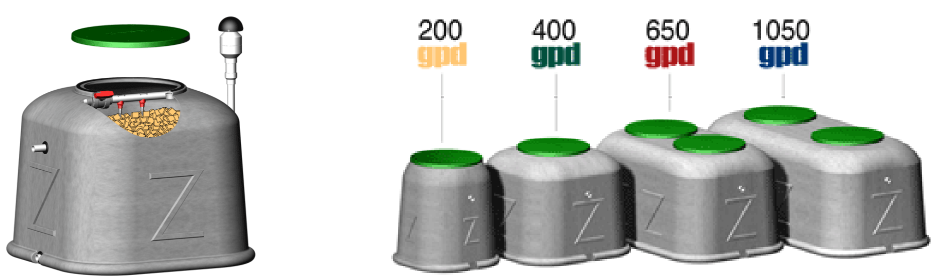


Figure 6-14
The SCAT advanced wastewater treatment system (left) comes preassembled for easy installation and in a range of sizes (right). (Adapted from Zabel Environmental Technology, Inc.)

Contact
Zabel Environmental Technology
PO Box 1520
Crestwood, KY 40014
Phone (502) 992-8200
(800) 221-5742
Fax (502) 992-8201
Web www.zabelzone.com

6-3.6 SeptiTech™ wastewater pre-treatment systems

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, and pathogen reduction
Applications	Single home and small community residential systems

Background

The SeptiTech system is composed of a standard two chamber septic tank, a multi-pass trickling biofilter module, and an effluent distribution system (pressure drainfield or UV disinfection and drip irrigation). Hydrophobic polystyrene beads are used as the medium for fixed film growth.

Description of process

Clarified septic tank effluent flows by gravity into the recirculation chamber of the SeptiTech unit. A submerged pump periodically sprays wastewater onto the attached growth process and the wastewater percolates through the packing material. The treated water then flows back into the recirculation chamber and mixes with the contents, resulting in some denitrification. Treated water flows into a clarification chamber and is periodically discharged to an effluent management system. The system includes an integrated logic controller to modify the system operation for optimal treatment under varying loading conditions.

System footprint

Typical residential system will have a length of 8.5 ft, width of 5.5 ft, and height of 5.5 ft. Systems normally installed fully buried for cold protection or above ground if bedrock limits excavation.

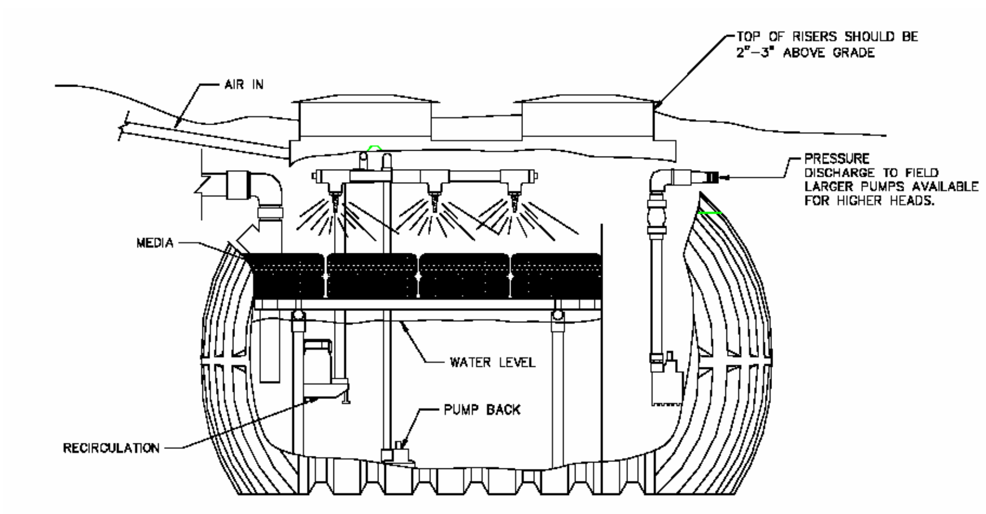


Figure 6-15

Diagram of the SeptiTech residential wastewater treatment system. (Adapted from Septitech, Inc.)

Advantages

System designed for low maintenance requirements. Integrated logic controller to optimize treatment under variable flow conditions. Optional UV disinfection and drip irrigation components. Designed for sites with seasonal use.

Disadvantages
Requires electricity for pump operation. Will require periodic sludge removal. System performance not well established.

Performance
Manufacturer performance claim of effluent BOD_5 and TSS concentrations of less than 10 mg/L, some nitrogen removal, and 2 log coliform removal.

Operation and maintenance
SeptiTech offers two year warranty and service contract included with purchase price of unit. After two years owner is given the option to extend this service contract. Manufacturer also advertises that homeowner will not be required to do any maintenance to this system, alarm will notify owner of any problems. Service contract provided for first two years, renewable thereafter. Relatively low service requirements.

Power and control
Power requirements include pumps and control panel. Annual power usage expected to range from 1,500 to 2,000 kWh.

Cost
$5,000 to 6,000, includes capital and installation costs for installation of biofilter component only. UV disinfection and drip irrigation systems will increase cost of system.

Contact
SeptiTech
220 Lewiston Road,
Gray. ME 04039
Phone (207)657-5252
Fax (207)657-5246
E septi@septitech.com
Web www.septitech.com
Model descriptions
M400 and M400UV (440 gal/d)
M500, M550, M550UV (660 gal/d)
M750, M750UV (880 gal/d)
Commercial models up to 50,000 gal/d
Vendor support
System comes with a two year warranty and service contract. Option to renew warranty after initial service agreement ends.

6-3.7 Waterloo biofilter®

Category	Secondary treatment
Technology	Trickling biofilter
Input	Settled wastewater, septic tank effluent
Function	Oxidation, nutrient transformation/removal, pathogen reduction
Applications	Individual, cluster, small community, commercial systems, and landfill leachate

Background
The Waterloo Biofilter was developed in Ontario for the treatment of domestic wastewater. The system has also been used for the treatment of wastewater from resorts, small municipalities, landfills, and food processing facilities. This system has been implemented in cold climates and in applications in which the treated water has been reused onsite.

Description of process
The medium used in the Waterloo Biofilter is an open-cell foam that is lightweight, has a high surface area, and is resistant to clogging. Settled wastewater is applied to the surface of the biofilter with a spray distribution system. The biofilter can be placed above ground or below ground according to site conditions and can be used in single-pass and multi-pass configurations. The basic system flow diagrams are shown in Fig. 6-16.

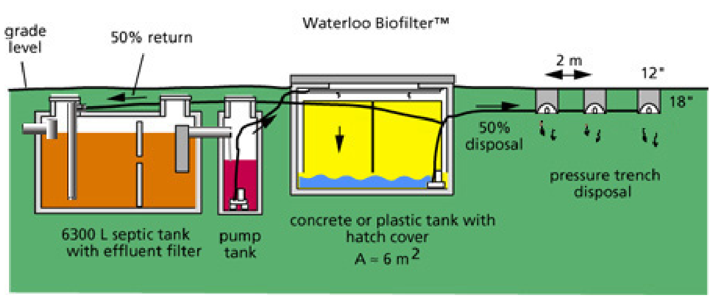
System Footprint
The typical system will have a surface area of 32 ft^2. System often housed in wooden shed with a length of 8 ft, width of 4 ft, and height of 5 ft. Systems can be installed above ground, partially buried, or fully buried.

Advantages
Relatively low maintenance, recovers quickly in event of process disturbance, adaptable to most sites including flow rate and unit placement, performs well in cold climates, can be used at sites with limiting site conditions, and has a small system footprint.

Disadvantages
Requires electricity for pump operation. Extended power failure can result in wastewater backup. May be more expensive than non-proprietary systems which use locally available medium.

Performance
The Waterloo Biofilter system has been included in many onsite demonstration projects. Typical treatment performance, after single-pass treatment of residential wastewater, is 90 to 95 percent removal of BOD_5, 90 to 95 percent removal of TSS, and 20 to 40 percent removal of TN. Forced aeration and multi-pass treatment typically improves treatment. Additional performance specifications from representative research studies are presented in Table 6-14.

Operation and maintenance
The Waterloo Biofilter system requires periodic maintenance. The system generally uses one or two submersible pumps to transport water to the biofilter system and to subsequent wastewater management operation, depending on site characteristics. The pump can be operated on a demand or timed basis. The pump and control panel should be inspected regularly along with other system components, including inspection and cleaning of the spray nozzles and medium. Under normal use conditions, the medium is not expected to clog or require changing for 20 to 30 years (manufacturer's claim). Systems should be inspected regularly for clogging of spray distribution system and overall system operation. Correct pump and control system operation should be confirmed.



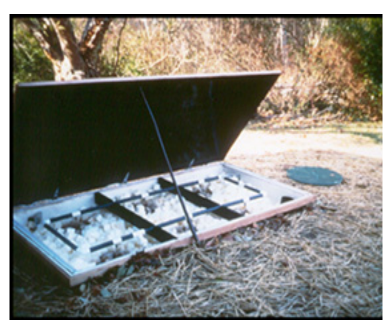


Figure 6-16

A diagram of the Waterloo Biofilter (left) and view of internal packing (right). (Adapted from Waterloo Biofilter Systems, Inc.)

Power and control
Generally uses one or two pumps depending on specific site characteristics and design. Alarm and monitoring equipment recommended, especially for large and/or remote systems. Can be dosed on a timed or demand basis. Annual power usage expected to range from 500 to 1000 kWh.

Cost
$7,000 to 8,000, includes capital and installation costs for installation of biofilter component only.

Table 6-14
Selected representative studies of Waterloo Biofilter performance

Parameter	Unit	Location of study		
		Massachusetts[a]	Acton, ON[b]	Gloucester, MA[c]
Description of system		Demonstration	Golf Club	Residential
HLR	gal/d	330	8000	
DF	dose/d	15		
Recirculation	unitless	2		2
System performance[d]				
BOD_5	mg/L	9.5 (92%)	3 (99%)	12 (93%)
TSS	mg/L	6.2 (87%)	3 (98%)	7 (87%)
Oil/grease	mg/L			
TN	mg/L	13.2 (63%)	10 (88%)	55.9 (28%)
NO_3-N	mg/L	9		23
NH_3-N	mg/L	1	0.5	26.5
P	mg/L		0.7 (89%)	8.4 (0%)
Fecal coliform	CFU/100 mL	1.5E4 (2.2)		1.0E3 (2)

[a] Massachusetts Alternative Septic System Test Center (2001) Evaluation of Waterloo Biofilter.
[b] Jantrania *et al*. (1998).
[c] Jowett (1997).
[d] Performance reported as average effluent concentration with average removal in parentheses for all parameters except for coliform, which is reported as geometric mean and log removal in parentheses.

Contact
Waterloo Biofilter Systems Inc.
143 Dennis Street, Rockwood
Ontario NOB 2K0
Phone (519) 856-0757
Fax (519) 856-0759
E craig@waterloo-biofilter.com
Web www.waterloo-biofilter.com
Model description
Designs and manufactures system components including effluent filter, biofilter, and soil adsorption system. Company also provides additional components for phosphorus removal, membrane filtration, and disinfection.

References and other resources

Jantrania, A.R., K.C. Sheu, A.N. Cooperman, and O.C. Pancorbo (1998) Performance Evaluation of Alternative Systems – Gloucester, MA, Demonstration Project, in *Proceedings of the Eight National Symposium on Individual and Small Community Sewage Systems,* Orlando, FL, American Society of Agricultural Engineering, St Joseph, MI.

Jowett, E.C., and M.L. McMaster (1995) On-Site Wastewater Treatment Using Unsaturated Absorbent Biofilters, *Journal of Environmental Quality*, Vol. 24, Pp. 86-95.

Jowett, E.C. (1999) Immediate Re-Use Of Treated Wastewater for Household and Irrigation Purposes, Presented at 10th Northwest On-Site Wastewater Conference, University of Washington, Seattle, September 21, 1999.

Jowett, E.C., J.D. Redman, F.C. Ford, S. Klint, G.L. Prentice, and C.P. Hughes (1999) Bio-Remediation Of Landfill Leachate With Remote Monitoring And On-Site Disposal, *Battelle Conference Proceedings*, San Diego, April 1999.

Jowett, E.C., W.G. Cook, G.L. Prentice, C.P. Hughes, F.C. Ford, and S. Klint (1997) Removal Of VOCs From Landfill Leachate Using Absorbent Aerobic Biofiltration, *American Chemical Society*, Ninth Annual Symposium on Emerging Technologies in Hazardous Waste Management, Pittsburgh, September 15-17, 1997.

Jowett, E.C., D.A. Manz, B. Kim, S. Kim, and F.C. Ford (1998) Communal-Size Sewage and Leachate Treatment Using Waterloo Biofilters in Process Trains, Environmental Science and Engineering, January 1998, p. 36-37.

Jowett, E.C. (1997) Sewage And Leachate Wastewater Treatment Using The Absorbent Waterloo Biofilter, Site Characterization and Design of On-Site Septic Systems", ASTM STP 1324, M.S. Bedinger, J.S. Fleming, and A.I. Johnson, Eds., American Society for Testing and Materials, West Conshohoken, PA 1997, p. 261-282.

Jowett, E.C., and D. Pask (1997) Innovative Septic Systems and Nutrient Removal Technologies in Canada and the United States, In: 9th NW On-Site Wastewater Treatment Short Course, University of Washington, September 22, 1997.

Jowett, E.C. (1997) Design And Start-Up Of Domestic Wastewater Re-Use System In The CMHC Toronto 'Healthy House', National Onsite Wastewater Recycling Association 6th Annual Conference, October 24, 1997, College Station, Texas.

Millham, N.P., G. Heufelder, B. Howes, and J. Costa (2000) Performance of Three Alternative Septic System Technologies and a Conventional Septic System, *Environment Cape Cod*, Vol. 3, No. 2, Pp. 49-58.

Townshend, A.R., E.C. Jowett, R.A. LeCraw, D.H. Waller, R. Paloheimo, C. Ives, P. Russell, and M. Liefhebber (1997) Potable Water Treatment And Reuse Of Domestic Wastewater in the CMHC Toronto 'Healthy House', Site Characterization and Design of On-Site Septic Systems, ASTM STP 1324, M.S. Bedinger, J.S. Fleming, and A.I. Johnson, Eds., American Society for Testing and Materials, West Conshohoken, PA 1997, p. 176-187.

US patents 5,707,513; 5,980,739; and 5,762,784. This technology is also licensed to several other companies including Zabel (Aerocell), Links-Loo Inc, and ACP Inc. (Eco-Nomad).